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August 17, 1994

Lisa Price  
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via Federal Express

**RE: Transmittal of Treatability Study Report for the Crystal Chemical Superfund Site, Houston TX**

Dear Lisa:

Enclosed please find a copy of the report entitled "*Treatment of Arsenic-Contaminated Groundwater from the Crystal Chemical Superfund Site*". This document was prepared to satisfy the Administrative Order on Consent which requires the submittal of a Treatability Study report.

If you have any questions regarding this document contact me at the number given above.

With Best Regards,

A handwritten signature in dark ink, appearing to read "Paul", followed by a horizontal line.

Paul Kuhlmeier

Attachment

cc: Aniko Molnar, SP  
Greg Shepherd, SP  
Dave Long, SP  
Steve Lange, Industrial Compliance

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**TREATMENT OF ARSENIC-  
CONTAMINATED GROUNDWATER FROM  
THE CRYSTAL CHEMICAL SUPERFUND SITE  
HOUSTON, TEXAS**

**Prepared By:**

**Southern Pacific Transportation Company  
Environmental Affairs Group  
Boise, Idaho**

**and**

**Hazen Research  
Golden, Colorado**

**August 17, 1994**

**TREATMENT OF ARSENIC-CONTAMINATED  
GROUNDWATER FROM THE CRYSTAL CHEMICAL  
SUPERFUND SITE**

008353

**Primary Authors:**

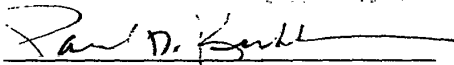
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## INTRODUCTION

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Past operating practices at the former Crystal Chemical plant resulted in the introduction of inorganic and organic species of arsenic to shallow groundwater. The U.S. Environmental Protection Agency's (EPA) Record of Decision (ROD) for the site required the hydraulic extraction of groundwater and its subsequent treatment prior to discharge. This document presents a summary of all wastewater treatment technologies investigated that can remove complex arsenic forms from water. It also serves as the treatability study deliverable required under an Administrative Order on Consent entered into between the EPA and Southern Pacific Transportation Company (SPTCo). The program described here was designed by the Southern Pacific Environmental Affairs Group and executed by Hazen Research Inc., Golden, Colorado.

In April of 1993 the SPTCo Environmental Affairs Group devised a research plan to develop a cost-effective, simple process for removing a complex mixture of arsenic species from contaminated groundwater at the Crystal Chemical Superfund site. This report is an accumulation of a three-phase research program for the characterization of contaminated groundwaters, development of analytical procedures, screening of remediation processes, and optimization of a recommended treatment system. In Phase I, the target arsenic effluent concentration was 50 parts per billion (ppb), the maximum contaminant level (MCL) under the federal Safe Drinking Water Act. Such a goal was originally derived in consideration of potential reinjection of the treated water into a shallow aquifer.

The treatment target was increased to 200 ppb arsenic in Phase II to evaluate ferric coprecipitation treatment programs to comply with a National Pollutant Discharge Elimination System (NPDES) permit in which treated water is discharged to the storm sewer system. In a final series of tests under Phase II, the treatment goal was increased to 2 parts per million (ppm) to comply with a Publicly Owned Treatment Works (POTW) permit in which treated water is discharged to a municipal sewer. SPTCo applied and has subsequently received a permit to discharge pretreated groundwater to a City of Houston POTW at an average total arsenic concentration of 2 ppm (3 ppm on grab sampling). In Phase III, a nonoxidative ferric coprecipitation treatment program was optimized to accommodate various levels of arsenic contamination to produce an effluent with less than 2 ppm total arsenic. A block flow diagram of the test plan is provided in Figure 1.

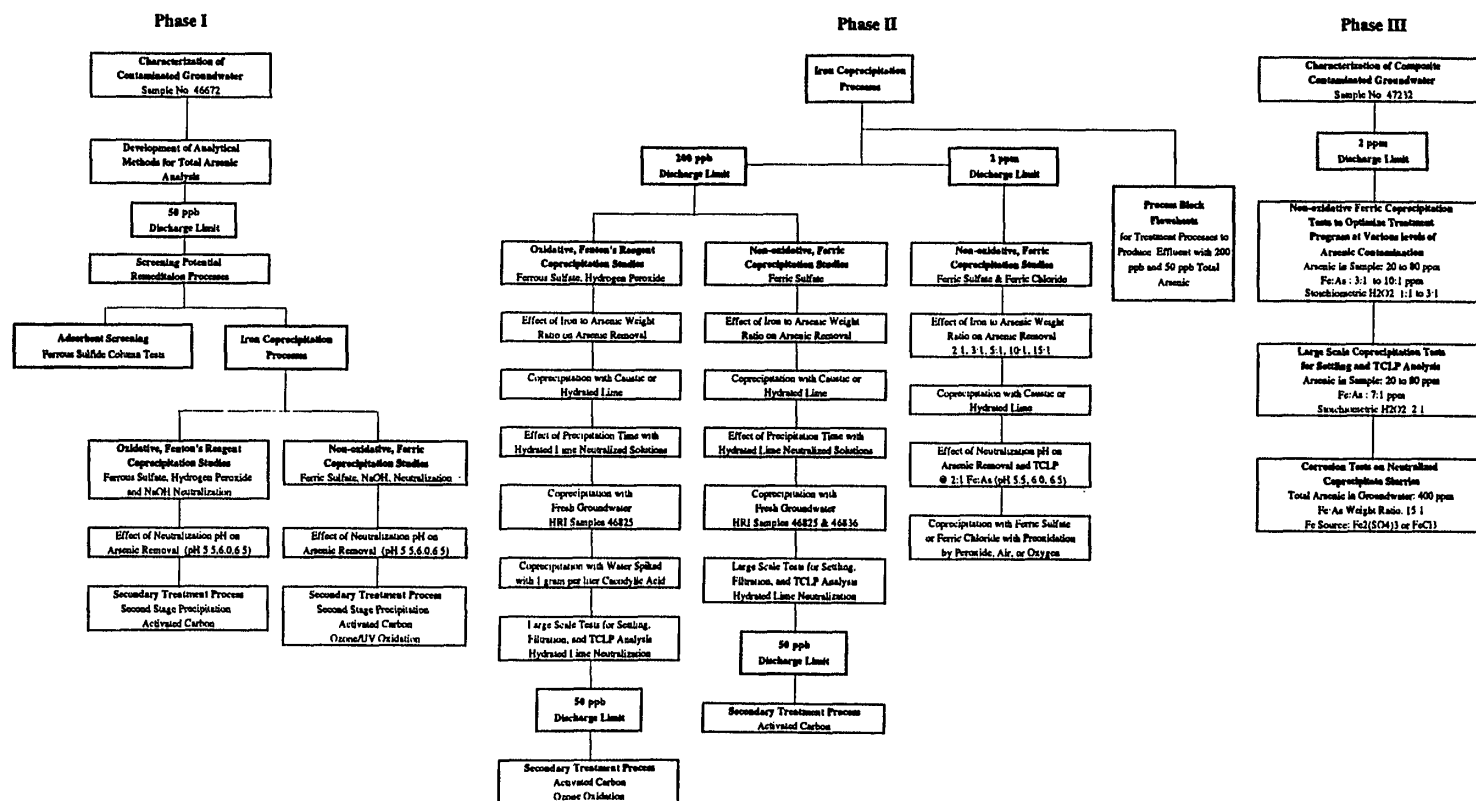


Figure 1. Test Plan for the Development of Remediation Program for Arsenic at Crystal Chemical Superfund Site

## BASIS OF STUDY

Monosodium methylarsenate, the primary product manufactured at the facility is derived from arsenic trioxide. Groundwater speciation data collected throughout this study has demonstrated that four forms of arsenic are present in groundwater; arsenate, arsenite, monomethylarsenic acid and dimethylarsenic acid. Literature is unavailable on treatment of the organo- forms which comprise over two thirds the resident arsenic mass, with the notable exception of a site in Vineland, New Jersey (Harper and Kingham, 1992). As such, this program was developed based on processes known to be potentially effective at removing inorganic arsenic species. Several methods have been developed to extract arsenic from aqueous solutions. Four process types dominate, they are adsorption, ion exchange, membrane separation, and chemical precipitation (Higgins and Romanow, 1987; Krapf, 1981). Of these, chemical precipitation is the most commonly used on an industrial scale. All of these technologies except membrane separation were investigated. Considerable discrepancies exist in the literature as to the success of most of these methods. Two aspects of all but the Vineland Chemical report are consistent, arsenic is in the inorganic form, and only minor amounts of arsenic (<1.0 mg/l) in the influent are being investigated. Neither of which are germane to the Crystal Chemical site.

Membrane technologies were determined to be cost prohibitive and difficult to control (Buckley et al., 1989, Le et al., 1989). Hollo et al., (1968) concluded ion exchange resins were ineffective at removing arsenic. Researchers at the Vineland Chemical facility tested activated alumina for treatment of arsenical pesticides (Mookerjee, 1977). Mookerjee (1977) observed good total arsenic removal at influent concentrations below 10 ppm but not at higher concentrations. He also found that regeneration posed a problem because each regeneration resulted in a substantial loss of adsorptive capacity. Sodium aluminate formation in the regeneration process was also a problem. Lee and Rosehart (1972) reported anionic resins such as Amberlite 400 were effective at reducing arsenic if kept in a pH range of 2 to 3. They also found at the bench scale level, arsenic can be removed by a strong base resin at a pH of 5.0, and that activated carbon was relatively effective at a pH of 4.0. More work was done on the efficacy of adsorbents by Gupta and Chen (1978) who considered activated alumina, activated bauxite, and activated carbon again at the bench scale level. Their study indicated that activated alumina could achieve over 95 percent As (V) and As (III) removal twice as efficiently as activated bauxite and 12 times more efficiently than activated carbon. Activated alumina removed As (V) over 20 times more efficiently than As (III). Similar trends were evidenced with the other adsorbents. This interpretation was generally consistent with the findings of Bellack (1971) as well. Lee and Rosehart (1972) tried filtering water containing minor amounts of arsenic through a ferric sulfide bed with results on par with the activated alumina. Apparently the beds were never upscaled for field evaluation.

With the work of past studies in mind SPTCo decided to evaluate one step unit processes first, in an attempt to develop a simple treatment system. After the first phase of study it became apparent that such a process was not viable for the Crystal Chemical wastewater stream. In all, three phases of studies were carried out, each building on the previous phase until an optimum design was determined. Treatment goals attempted ranged from 0.050 ppm to 2.0 ppm, representing federal MCLs and City of Houston pretreatment standards, respectively. The lowest treatment goal was only achieved by an elaborate combination of secondary and tertiary processes, but it was not believed to be either economically viable or practically achievable on a full scale basis.

Phase I evaluated adsorption, ion exchange, and sulfide filtration. Phase II and III focused on chemical precipitation methods as Phase I results indicated that the complex nature of the various arsenic species and the high concentrations present, precluded the use of a single unit process and also showed the relative inefficiency of adsorption and ion exchange processes. Attempts were made to treat the waste stream with and without preoxidation. Several types of precipitant were also considered, including iron sulfate, iron chloride, and lime. It was determined that both iron chloride and sulfate would meet POTW effluent standards and the ultimate choice for full scale use will depend on operating cost and corrosion considerations.

This document has been written in a compartment type manner. A comprehensive summary of the entire program is provided first for those readers interested primarily in techniques applied and the overall results achieved. A detailed discussion of each phase is then presented in succession. Materials, methods, and conclusions are discussed for each phase in turn. All treatment diagrams are conceptual in nature. Results of this treatability program are being used to assist in the design of a full scale treatment plant.

## CONDENSED SUMMARY OF FINDINGS

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### PHASE I

#### Groundwater Characterization

A drum of arsenic-contaminated water from the Crystal Chemical Superfund site was shipped to Hazen Research in Golden, Colorado for characterization and testing. The water contained 150 ppm total arsenic, of which approximately 50% was in the form of organic-arsenic compounds. The most effective methods of analyzing total arsenic from solutions containing organic-arsenical compounds were determined to be inductively-coupled plasma spectroscopy for total arsenic levels greater than 1 ppm and graphite furnace atomic absorption (GFAA) for levels below 1 ppm.

#### Screening of Adsorbents

Initial tests under Phase I were conducted on various adsorbent materials to evaluate the potential of a single-pass bed of adsorbent to achieve a target effluent concentration of 0.050 ppm. Adsorbents tested were activated carbon, activated alumina, ferrous sulfide, and a strongly basic ion exchange resin. Ferrous sulfide produced the lowest effluent arsenic concentration, 18.4 ppm. Activated alumina showed moderate activity, producing an effluent with 82 ppm total arsenic.

Two column tests were conducted with ferrous sulfide to further investigate possible treatment applications. Although these tests exhibited absorption of arsenic from contaminated groundwater, the loading capacities were too low to make this method practical.

#### Ferric Coprecipitation

In the second series of tests, bench-top beaker studies were conducted to evaluate the efficacy of ferric coprecipitation for the removal of arsenic from contaminated groundwater. Coprecipitation involves the adsorption of arsenic compounds onto rapidly growing ferric hydroxide particles. The arsenic contaminants are mechanically trapped within subsequent layers of the rapidly precipitating iron floc. The coprecipitation process consists of treating contaminated groundwater with soluble iron and adjusting the pH level to less than 2.5 to assure complete iron dispersion. Coprecipitation occurs when the iron-treated solution is neutralized with either sodium hydroxide or hydrated lime, causing the formation of ferric hydroxide precipitates.

Two coprecipitation processes were investigated. Initial tests were conducted on an oxidative treatment program using Fenton's reagent to destroy organic-arsenical compounds, followed by coprecipitation of arsenic with iron. Fenton's reagent is a mixture of hydrogen peroxide and ferrous iron which produces hydroxyl free radicals (a powerful oxidizing agent). A single-stage Fenton-type coprecipitation procedure reduced the arsenic level in contaminated groundwater from 150 ppm to 0.170 ppm. The treatment levels in this test were ferrous iron at 15.4 times the initial weight of arsenic and 5.4 times the stoichiometric amount of hydrogen peroxide needed to oxidize ferrous to ferric iron.

A nonoxidative ferric coprecipitation treatment program was also evaluated. The purpose of these tests was to determine if destruction of organic-arsenical compounds is necessary for effective coprecipitation of arsenic. In one of these tests, contaminated groundwater was treated with ferric sulfate at a 10:1 iron-to-arsenic weight ratio, stirred for ten minutes, and neutralized to pH 5.5 with sodium hydroxide. This test produced a supernatant with a total arsenic content of 0.290 ppm. At a similar treatment level (10.2:1 iron-to-arsenic weight ratio and neutralization pH of 5.4), an oxidative Fenton-type coprecipitation program developed an effluent with a total arsenic concentration of 0.260 ppm.

These results illustrated that preoxidation of organic-arsenical compounds with a Fenton-type reaction will only slightly increase the effectiveness of the ferric coprecipitation procedure in groundwaters containing both organic and inorganic arsenic compounds. Similar results were obtained in a series of second-stage coprecipitation tests in which a sample of first-stage coprecipitation supernatant containing 0.150 ppm total arsenic was treated in either oxidative or nonoxidative processes. The Fenton-type, oxidative coprecipitation procedure produced a filtered supernatant containing 0.110 ppm total arsenic. The nonoxidative process developed a slightly higher arsenic level of 0.120 ppm.

Optimum arsenic removal was achieved at a neutralization pH of 6.0 with both oxidative and nonoxidative coprecipitation treatment programs. Samples of contaminated groundwater were treated with either ferric iron or hydrogen peroxide and ferrous iron and neutralized to pH 5.5, 6.0, and 6.5 with sodium hydroxide. A slight reduction in total arsenic levels was noted when the pH of the neutralized solutions increased from 5.5 to 6.0. A further increase in neutralization pH from 6.0 to 6.5, however, increased the total arsenic in the supernatant.

Filter cakes of precipitated solids from both an oxidative Fenton-type coprecipitation and nonoxidative ferric process were dried and submitted for organic carbon analysis. The results of the organic carbon analysis indicated that precipitated solids from a Fenton-type treatment contained 0.49% organic carbon, while the ferric precipitated solids had 0.87% organic carbon.

TCLP analyses of dried precipitated solids from both coprecipitation processes indicated leachate arsenic



levels below the 5 ppm regulatory limit.

### **Secondary/Tertiary Processes**

Tests were conducted to investigate the use of secondary/tertiary treatment processes to reduce the arsenic content in effluent from an oxidative or nonoxidative ferric coprecipitation treatment to the target level of less than 0.050 ppm. A semiquantitative analytical technique indicated no inorganic arsenic in the coprecipitate supernatant. Polishing treatments were selected for the adsorption or oxidation of organic-arsenical compounds. Two process were investigated: activated carbon adsorption and oxidation by ozone and ultraviolet radiation.

#### **Activated Carbon**

Treating supernatant from a single-stage Fenton-type coprecipitation with ten weight percent activated carbon reduced the total arsenic from 0.170 to 0.100 ppm. Supernatant from a nonoxidative ferric program demonstrated reduction in total arsenic from 0.630 to 0.510 ppm. Optimum arsenic removal was achieved with a two-stage Fenton-type coprecipitation, followed by activated carbon to produce a filtrate containing 0.050 ppm total arsenic. Although this elaborate system was successful in reaching 0.05 ppm, it did not appear that the system results could be routinely reproduced at the laboratory scale.

#### **Ozone or Ultraviolet Radiation Oxidation**

A series of tests was conducted to investigate the oxidation efficiency of ozone and ozone with ultraviolet radiation for the destruction of organic-arsenical compounds. Tests were conducted on solutions which were spiked with an organic-arsenical compound (cacodylic acid) at pH levels adjusted to 4 or 8. Analysis of the resulting solutions indicated no oxidation of the organic-arsenical surrogate. A spiked solution treated with both O<sub>3</sub> and UV, however, developed approximately 80% conversion of cacodylic acid to inorganic arsenic in one hour. Additional ozone studies were conducted in Phase II.

### **PHASE II**

Phase II was initiated to further investigate the ferric coprecipitation treatment process to reduce the arsenic content in contaminated groundwater to less than 200 ppb for effluent discharge to a storm sewer (NPDES permit). Both the nonoxidative ferric and oxidative Fenton-type treatment programs were investigated. Tests were conducted to optimize conditions for the coprecipitation processes and

collect information on the settling characteristics and filterability of coprecipitate solids. Additional studies were conducted to investigate second-stage activated carbon and ozone oxidation procedures to produce an effluent with a total arsenic content of less than 50 ppb. Preliminary flowsheets were developed for treatment processes to produce treated water containing either 200 or 50 ppb total arsenic.

Beaker tests were also performed to examine a nonoxidative coprecipitation treatment program to achieve an elevated goal of 2 ppm total arsenic for discharge to a municipal sewer. Variables investigated in these tests included iron-to-arsenic weight ratio, source of ferric iron, neutralizing reagent, neutralizing pH, and stability of solid product.

### **Nonoxidative Ferric Coprecipitation for 200 ppb Arsenic Discharge Limit**

A nonoxidative ferric iron coprecipitation treatment program was examined in a series of bench-top beaker tests. Ferric sulfate was used as the source of iron in these tests. Variables investigated in these studies included degree of groundwater oxidation, iron-to-arsenic weight ratio, coprecipitation with sodium hydroxide or hydrated lime, and precipitation time.

#### **Degree of Groundwater Oxidation**

Coprecipitation tests were conducted with aged and fresh groundwater samples. The aged groundwater had been shipped to Hazen for Phase I testing and exposed to air for several months prior to initiating the Phase II test program. Since arsenite will slowly oxidize to arsenate when exposed to air, it was believed that the sample was no longer representative of contaminated groundwater at the subject facility. Since the ferric coprecipitation process does not effectively remove arsenite from contaminated waters, a series of tests was conducted to evaluate the efficacy of the treatment on both aged and fresh groundwater samples. These tests showed that significantly lower arsenic levels were achieved with the aged sample. The fresh groundwater produced an average filtered effluent with 30 ppm total arsenic. Under similar conditions, the filtered effluent from the aged groundwater contained around 130 ppb total arsenic.

In a second series of tests, hydrogen peroxide was added to an aliquot of fresh groundwater to oxidize arsenite to arsenate prior to addition of the ferric treatment. A control with no hydrogen peroxide was conducted concurrently. Supernatant from the peroxide-treated solution contained 210 ppb total arsenic. The control solution developed a treated arsenic level of 17 ppm. These results indicate that, in order to effectively remove arsenic from unoxidized groundwater, an oxidizing agent should be added to the feed solution prior to coprecipitation.

### **Iron-to-Arsenic Weight Ratio**

The effect of iron treatment level on the efficacy of the ferric coprecipitation process was investigated at three iron-to-arsenic weight ratios (10:1, 20:1, and 30:1). The results of these tests indicated that increased arsenic removal was achieved at elevated iron treatment levels. The total arsenic concentration in the effluent from the 10:1 iron-to-arsenic treatment level was above the 200 ppb target limit.

### **Neutralization with Sodium Hydroxide or Hydrated Lime**

Hydrated lime consistently produced lower effluent total arsenic levels than did sodium hydroxide neutralization in duplicate studies.

### **Precipitation Time**

Previous studies under this project indicated precipitation of calcium sulfate in filtrates from treated solutions which were agitated for 30 minutes after neutralization with hydrated lime. Crystalline precipitates appeared after clear filtrates were allowed to remain undisturbed overnight.

A series of two tests was conducted to investigate the effect of coprecipitation time on supernatant calcium and sulfate levels. In these tests, contaminated groundwater samples (150 ppm total arsenic) were treated with ferric iron at a 15:1 iron-to-arsenic level and neutralized to pH 6.0 with hydrated lime. After neutralization, the solutions were agitated for either 30 minutes or 24 hours, flocculated, and the supernatant filtered. Samples of filtrate from both tests were analyzed for calcium and sulfate content. Filtrate from the 30-minute coprecipitation study contained 1,004 ppm calcium and 2,350 ppm sulfate. The 24-hour coprecipitation test, on the other hand, developed lower calcium and sulfate levels of 846 and 1,860 ppm, respectively. These results indicate that increased agitation time of coprecipitate slurries neutralized with hydrated lime will increase the precipitation of calcium sulfate, as evidenced by lower soluble calcium and sulfate levels in treated supernatant. The total arsenic level in the supernatant was also reduced at the longer coprecipitation time.

### **Oxidative Fenton Reagent Coprecipitation for 200 ppb Arsenic Discharge Limit**

The oxidative, Fenton-type coprecipitation treatment program (ferrous sulfate and hydrogen peroxide) examined bench-top beaker studies. The results from these tests were similar to the previously discussed nonoxidative ferric coprecipitation tests with increased arsenic removal at elevated iron-to-arsenic weight ratios and longer agitation times of slurries neutralized with hydrated lime. Overall, slightly lower effluent arsenic levels were achieved with the oxidative coprecipitation process.

### **Fenton Coprecipitation with Water Spiked with 1,000 ppm Organic-Arsenic**

Solutions spiked with one gram cacodylic acid (demethylarsenic acid) per liter were treated in a Fenton-type coprecipitation program at 15:1 and 20:1 iron-to-arsenic weight ratios. After oxidation with hydrogen peroxide and neutralization with hydrated lime, the 15:1 ratio produced a filtrate containing 1.88 ppm total arsenic. The treatment using a 20:1 ratio developed a filtrate with 1.09 ppm total arsenic. TCLP analysis of a combined filter cake produced a leachate containing 45.6 ppm total arsenic, far above the 5 ppm regulatory limit.

### **Secondary Ozone Treatment Processes for 50 ppb Discharge Limit**

A series of tests was conducted to determine if ozone oxidation can effectively reduce the arsenic levels in single-stage coprecipitation supernatant to less than 50 ppb for reinjection of treated water. Demonstration of a second-stage ozone oxidation process indicated destruction of organic-arsenical compounds. In these tests, the pH level of the first-stage supernatant (containing 111 ppb total arsenic) was adjusted to 10 prior to ozone treatment. Inorganic arsenic was then removed from the ozone-treated solution by ferric coprecipitation or adsorption on activated carbon to produce an effluent with a total arsenic level of less than 5 ppm.

### **Nonoxidative Coprecipitation to Achieve 2 ppm Arsenic Discharge Limit**

A nonoxidative coprecipitation treatment program was developed to provide an elevated target arsenic level of 2 ppm for discharge to a municipal sewer under a POTW permit. Variables investigated were iron-to-arsenic weight ratio, source of ferric iron, neutralizing reagent, neutralizing pH, oxidizing agent, and leachability of the solid products.

#### **Iron-to-Arsenic Weight Ratio**

The effect of iron-to-arsenic weight ratio on effluent arsenic level was investigated in a series of bench-top beaker tests. Samples of fresh groundwater were treated with hydrogen peroxide and solid ferric sulfate. The solutions were neutralized with either sodium hydroxide or hydrated lime. Five iron-to-arsenic weight ratios were investigated (2:1, 3:1, 5:1, 10:1, and 15:1). Results from these tests indicated that iron-to-arsenic weight ratios as low as 2:1 can reduce the arsenic level in contaminated groundwater from 150 to less than 2 ppm. At this treatment level, the supernatant from the solution neutralized with hydrated lime contained 1.04 ppm total arsenic, while the supernatant from the solution neutralized with sodium hydroxide contained 1.34 ppm total arsenic.

### 7:1 Iron-to-Arsenic Weight Ratio

Tests were conducted to evaluate the effects of iron source (ferric sulfate and ferric chloride) and oxidizing agent (hydrogen peroxide, oxygen or air) on coprecipitation efficacy. In the initial two tests, fresh contaminated groundwater samples were treated with peroxide (to oxidize arsenite to arsenate) and either ferric sulfate or ferric chloride. The solutions were neutralized to pH 6.0 with hydrated lime, and supernatant was analyzed for total arsenic content. Supernatant from the solution treated with ferric sulfate contained 0.41 ppm total arsenic. The solution treated with ferric chloride produced a supernatant with a total arsenic content of 0.29 ppm. Both iron treatments produced precipitate solids that passed TCLP protocol.

In a second series of tests at the 7:1 iron-to-arsenic treatment level, samples of fresh groundwater were oxidized by either air or oxygen prior to addition of ferric chloride. Neither of these oxidants proved as effective as hydrogen peroxide for the conversion of arsenite to arsenate.

### PHASE III

In the final phase of this project, treatment conditions were optimized for a ferric-based coprecipitation process to treat contaminated groundwater to a target arsenic level of 2 ppm for discharge to a municipal sewer under a POTW permit. Bench-top beaker tests were conducted to quantify the effect of iron-to-arsenic weight ratio, iron source (ferric sulfate and ferric chloride), and hydrogen peroxide stoichiometry on arsenic removal at various levels of arsenic contaminations.

Test solutions were prepared by blending a composite groundwater sample containing 83 ppm total arsenic with uncontaminated groundwater. The levels of arsenic contamination were 83, 42, and 21 ppm.

The results of these tests demonstrated that arsenic-contaminated groundwaters were successfully treated at a 7:1 iron-to-arsenic weight ratio and two times stoichiometric hydrogen peroxide (based on oxidation of arsenite to arsenate) to produce an effluent with less than 2 ppm total arsenic. In these tests, solutions were acidified to less than 2.5 after addition of the ferric treatment to provide good dispersion of the iron prior to neutralization and precipitation. These conditions produced precipitate solids which passed the TCLP protocol.

Large-scale batch coprecipitation tests indicated that  $\text{FeCl}_3$ -treated waters produced clear supernatants under conventional clarifier conditions. A solids-contact clarifier may be required to produce clear overflow from  $\text{Fe}_2(\text{SO}_4)_3$ -treated solutions.

## PHASE 1 Screening of Adsorbents

### OVERVIEW

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A 55-gallon drum of groundwater from Monitoring Well No. 22 was shipped to Hazen for testing. The sample contained approximately 150 milligrams total arsenic per liter (mg/l), of which approximately 50% was in the form of organic-arsenic compounds. Some analytical method development work was required to account for the organic-arsenic compounds in the groundwater, since these compounds are quite resistant to oxidation in most digestion procedures. The most effective means of analyzing for total arsenic were determined to be inductively-coupled plasma (ICP) spectroscopy for levels greater than 1 part per million (ppm) and graphite furnace atomic absorption (GFAA) for arsenic levels below 1 ppm. Neither of these techniques requires a digestion.

Initially, tests evaluated the effectiveness of various adsorbent materials in the hope that a simple, single-pass bed of adsorbent could be used. Although several of the adsorbents removed some arsenic, none except ferrous sulfide was sufficiently effective to warrant follow-up studies. Two small ferrous sulfide column tests, run under different conditions, removed arsenic from the groundwater, but not to the levels and loading capacities needed to make this method practical.

As discussed in the introduction to this report previous work by others has shown that coprecipitation with iron effectively removes inorganic arsenic from water solutions. However, the presence of organic-arsenic compounds limits the effectiveness of this reaction. A series of tests was conducted to evaluate a process in which the organic compounds were destroyed with a powerful oxidant called Fenton's reagent (a mixture of hydrogen peroxide and ferrous iron) prior to coprecipitation. Using a procedure employing this reagent, arsenic was reduced to 170 ppb in the treated liquor. Coprecipitation without an oxidative pretreatment produced a liquor containing 260 ppb arsenic. A two-stage Fenton-type coprecipitation procedure produced a supernatant containing 110 ppb total arsenic. The arsenic level was further reduced to less than 50 ppb upon treatment with activated carbon. Iron-arsenic precipitates, with and without oxidative pretreatment, were below EPA standards for arsenic in the toxicity characteristic leaching procedure (TCLP) extract.

Preliminary tests with a second-stage oxidative process, utilizing ozone ( $O_3$ ) and ultraviolet (UV) radiation, show approximately 80% destruction of an organic-arsenic surrogate (cacodylic acid) in one hour. It is anticipated that this oxidation, when combined with ferric hydroxide coprecipitation, may achieve 50 ppb or less.

## TEST METHODS AND RESULTS

### ANALYTICAL RESULTS OF CONTAMINATED GROUNDWATER

A 55-gallon drum from the Crystal Chemical facility was, upon receipt at Hazen, assigned the Hazen Research Identification Number (HRI No.) 46672. The contents of the barrel were stirred, and a five-gallon sample was removed. Because the sample contained suspended solids, a portion of the sample was filtered through a 0.45-micron membrane filter. Analyses of filtered and unfiltered samples are summarized in Table 1.

Table 1. Analysis of Groundwater Sample

Constituent	Unfiltered	Filtered
Ba, ppm	<1	<1
As, ppm	150	149
Fe, pm	5	2
Al, ppm	5	<5
Pb, ppm	2	2
Ni, ppm	<1	<1
Mn, ppm	<1	<1
SO <sub>4</sub> , ppm	500	450
Cl, ppm	1,960	1,960
TOC, ppm	21	27
Ca, ppm	417	425

Analysis of the precipitated solids indicated 4.2 weight percent iron and 0.1 weight percent arsenic.

## SCREENING OF ANALYTICAL METHODS FOR TOTAL ARSENIC ANALYSIS

At the onset of this project, it was believed that all arsenic in the groundwater was present as inorganic arsenate ( $\text{As}^{+5}$ ) and arsenite ( $\text{As}^{+3}$ ) salts. Hydride formation atomic absorption (Hydride AA), a method approved by EPA, was selected for the arsenic analysis. The initial bottle roll and precipitation tests, reported in the next section, utilized this method to evaluate treatment efficiencies. Shortly thereafter, results from speciation analysis by another laboratory indicated that organic-arsenic compounds were present in the groundwater sample. Significant amounts of methanearsonic acid (MMAA) and cacodylic acid (DMAA) were detected. Since Hydride AA does not account for organic-arsenic compounds, a test program was initiated to evaluate various analytical techniques, and digestion procedures to recover organic-arsenic compounds were evaluated.

Spike samples of DMAA were prepared at 100, 200, and 300 ppm (as arsenic) and submitted for inductively coupled plasma (ICP) and Hydride AA analysis. The ICP samples were not digested prior to analyses, while the Hydride AA samples were digested by fuming with  $\text{HNO}_3$ ,  $\text{HClO}_4$ ,  $\text{HCl}$ , and  $\text{HF}$ . The results of these analyses are summarized in Table 2.

Table 2. Comparison of Methods for Total Arsenic Analysis

Spike Sample Concentration, ppm	ICP, ppm	Hydride AA, ppm
100	102	31.6
200	196	67.1
300	291	95.7

These results indicate that excellent recovery of organic-arsenic compounds was obtained with ICP analyses (2 to 3% variance from the spike concentration). Hydride AA detected approximately one-third of the total arsenic.

Three alternative digestion procedures were investigated to support the Hydride AA analysis. In this series of tests, a 50 ppm DMAA (as arsenic) standard solution was digested with hydrogen peroxide-sulfuric acid, permanganate-sulfuric acid, and chromic acid procedures. After digestion, the liquors were submitted for Hydride AA and ICP analysis. The results of these tests are presented in Table 3.



**Table 3. Comparison of Digestion Procedures for Total Arsenic Analysis, 50 ppm DMAA (as Arsenic) Standard Solution**

Digestion Procedure	H <sub>2</sub> O <sub>2</sub> /H <sub>2</sub> SO <sub>4</sub>	KMnO <sub>4</sub> /H <sub>2</sub> SO <sub>4</sub>	K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>
Hydride AA, ppm As	18.4	16.2	45.2
ICP, ppm As	43.3	43.4	48.1

These results indicate that the highest recovery of organic-arsenic compounds by Hydride AA is obtained with chromic acid digestion.

Additional screenings of perspective digestion procedures were conducted utilizing a simple semi-quantitative Gutzeit test apparatus to detect the presence of inorganic arsenic. In this test procedure, inorganic arsenic is liberated as arsine, AsH<sub>3</sub>, by zinc in an acid solution. The generated arsine produces a yellow-brown stain on test strips impregnated with mercury (II) bromide. For these tests, 1 ppm samples of DMAA were digested by peroxide and sulfuric acid. Complete conversion of organic arsenic was detected in a 10-gram (g) sample which was treated with 3 g of 1,000 g/l H<sub>2</sub>SO<sub>4</sub> and 1 g of 45% H<sub>2</sub>O<sub>2</sub>. The solution volume was initially reduced on a hot plate until fumes were generated, followed by boiling the fuming H<sub>2</sub>SO<sub>4</sub> for one minute. The boiling step was found to be important in destroying the DMAA. The H<sub>2</sub>O<sub>2</sub>/H<sub>2</sub>SO<sub>4</sub> procedure shown in Table 3 (above) did not include the boiling step.

UV radiation (4-watt lamp at 254-nanometer wavelength) also provided complete conversion of a 20-g DMAA spike treated with 1 milliliter (ml) of 45% H<sub>2</sub>O<sub>2</sub> and 1 ml H<sub>2</sub>SO<sub>4</sub> (1,000 grams per liter).

Three samples, spiked with DMAA at concentrations of 100, 1.0, and 0.50 ppm (as arsenic), were submitted for analysis by GFAA. This method provided acceptable arsenic recoveries of 103, 1.08, and 0.49 ppm, respectively.

Based on these tests, it was decided to use ICP to determine the total arsenic of waters with arsenic concentrations greater than 1 ppm. GFAA was used to determined low level arsenic concentrations (less than 1 ppm).

#### **BOTTLE ROLL TESTS TO SCREEN ADSORBENTS**

A set of bottle roll tests was conducted to evaluate the arsenic removal efficiencies of selected adsorbents. Four adsorbents were tested: activated carbon, activated alumina, ferrous sulfide, and IRA-400 (strongly

basic ion exchange resin). In these tests, four washed reagent bottles were each charged with adsorbent (5 g activated carbon, 5 g activated alumina, 10 g FeS, and 4.13 g IRA 400) and one liter of arsenic-bearing filtrate. Each bottle was stoppered with a one-hole stopper. The bottles were rotated for 22 hours. During the test, three samples were removed from each bottle and archived. Final samples were removed at the end of the test and vacuum filtered with a Gooch funnel, using a glass fiber filter. Filtrates were submitted for arsenic analysis. ICP analyses of the 22-hour samples are summarized in Table 4.

**Table 4. Results of 22-hour Bottle Roll Tests**

Absorbent	pH	Total As, ppm
Head	6.65	144
Al <sub>2</sub> O <sub>3</sub>	7.68	82.0
Carbon	7.75	135
FeS	7.95	18.4
IRA-400	7.93	136

These results indicate that none of the adsorbents were effective in removing arsenic to the 50 ppb target level. Ferrous sulfide produced the lowest effluent analysis, reacting and precipitating both inorganic arsenic and organic arsenic compounds. Activated alumina showed moderate activity. Two column tests, reported in the next section, were conducted with ferrous sulfide to further investigate possible treatment applications.

#### **FERROUS SULFIDE COLUMN TESTS**

Two column tests were conducted to further evaluate the arsenic adsorption activity of ferrous sulfide, using two arsenic-containing feed solutions. In the control test, the arsenic adsorption capacity of FeS was evaluated with untreated arsenic-bearing groundwater. For the second test, the groundwater sample was treated with 1,500 ppm NaOCl and the pH level adjusted to 5.5. The purpose of the test was to provide conditions that promote the oxidation of iron from ferrous to ferric at the surface of the FeS particles, thus increasing the amount of arsenic removal through the formation of ferric-arsenate precipitates.

For these tests, 100-ml burets were fitted with glass wool plugs and filled with 24 cubic centimeters (cc) of a slurry of 20- by 35-mesh FeS and deionized (DI) water. The FeS beds were rinsed with two bed volumes (BV) of DI water. The head space above the beds was filled with filtered groundwater, and 500-ml separatory funnels were placed on top of the burets. The funnels were filled with 250 ml of arsenic-bearing liquors. The flow rate through the FeS beds was adjusted to 1 BV per hour (24 cc per hour). Sample aliquots were collected every 15 minutes for the first hour and every half hour thereafter. The results of these tests are provided in Table 5.

**Table 5. Results of Ferrous Sulfide Column Tests**

Column Test with Untreated Arsenic Solution				Column Test with Arsenic Solution Treated with 1,500 ppm NaOCl, pH 5.5			
Time, Minutes	pH	EMF, mv	Total As in Effluent, ppm As	Time, Minutes	pH	EMF, mv	Total As in Effluent, ppm As
0 (Head)	8.25	244	149	0 (Head)	5.50		149
15	3.66	365		30	6.10	-55	
30	5.19	314		60	5.80	-45	
45	5.44			90	5.80	-40	
60	5.78			120	5.82	-35	5.3
90	7.66	310		150	5.99	-29	
120	8.13	297	73.8	180	6.03	-27	
150	8.47	282		210	6.03	-23	
180	8.50	267		240	6.07	-16	
210	8.58	262		270	6.09	-16	
240	8.57	252		300	6.13	-8	7.2
270	8.57	248					
300	8.30	246	115				

The results of these tests indicated that the treated water provided greater adsorption of arsenic. After 2 BV, the arsenic level in the effluent was reduced from 149 to 5.3 ppm. The concentration of the untreated solution was reduced to 73.8 ppm after 2 BV. The increased adsorption is most likely due to

increased ferric levels at the surfaces of the FeS particles. The reducing environment of the effluent from the treated feed column (as indicated by a negative EMF) is most likely due to formation of  $H_2S$ , which is produced when FeS is exposed to acidic solutions.

#### INITIAL FENTON'S REAGENT BEAKER TESTS

A series of beaker tests was conducted to evaluate the capability of Fenton's reagent to destroy organic-arsenic compounds, followed by coprecipitation of arsenic with iron. Fenton's reagent is a mixture of hydrogen peroxide and ferrous iron which produces hydroxide free radicals. Hydroxide-free radicals have been shown to be effective in the degradation of phenols, chlorophenols, formaldehyde, and octachloro-p-dioxin. This series of tests was initiated to determine if Fenton's reagent can be employed to destroy organic-arsenic compounds prior to coprecipitation of arsenic with iron.

In the first test, the pH of arsenic-bearing solution was adjusted to 3.0 with dilute  $H_2SO_4$ . After addition of 2,100 ppm ferrous iron (seven times stoichiometric), the pH of the solution dropped to 2.0. The pH was adjusted to 3.0 with dilute NaOH. Slight precipitation was noted upon addition of NaOH, and the solution became turbid. Hydrogen peroxide was then added slowly (14.66 g of 45%  $H_2O_2$ ). The pH of the solution fell to 2.5 upon addition of peroxide, and the solution became dark brown and began to fizz. Approximately 30 minutes after addition of peroxide, a light brown precipitate became dispersed in the solution. The fizzing stopped 45 minutes after peroxide addition. At one hour after peroxide addition, the pH of the solution was increased to 5.5 with dilute NaOH, and the resulting slurry was allowed to settle for 30 minutes. The clear supernatant was filtered through a 0.45-micron filter at a moderate filtration rate, and the filtrate was analyzed for As by GFAA. Results from this test indicate that the arsenic level was reduced from 157 to 0.29 ppm.

In the second test, the order of addition was reversed; peroxide (four times stoichiometric) was added first, followed by slow addition of ferrous sulfate (2,100 ppm ferrous). The results from this test showed that the arsenic concentration was reduced to 0.38 ppm. It is believed that through optimization of the process, the 200-ppb (0.2 ppm) target can be attained.

#### FENTON'S REAGENT OPTIMIZATION TESTS

Eight tests were conducted to determine reaction conditions for optimum arsenic removal in Fenton-type reactions with minimum consumption of reagents. These tests were defined by a statistical experimental design procedure to evaluate the relative effects of seven process variables: peroxide concentration, ferrous concentration, reaction pH, reaction time, order of reagent addition, precipitation stages, and final pH of precipitation slurry. The effects of each set of conditions were determined by the arsenic contents

in the final supernatants. An additional set of four tests was conducted to optimize reaction conditions. The conditions and results of these tests are summarized in Table 6.

During the initial series of eight tests, the pH of the test solutions was reduced to 3.0 prior to addition of Fenton's reagents (hydrogen peroxide and ferrous iron). Two methods of reagent addition were evaluated. One method involved addition of peroxide, followed by slow addition of iron and pH adjustment to 2.3 to 2.4 with dilute sulfuric acid. The other method prescribed the addition of iron first, followed by pH adjustment and slow addition of peroxide.

Treated solutions were agitated to either 20 or 40 minutes. Ferric iron and arsenic were coprecipitated upon pH adjustment to around 5.4 with dilute NaOH. Two precipitation procedures were investigated. In the single-stage process, the pH of the test solutions was elevated to either 5.3 or 5.5 through continuous addition of NaOH. The multi-stage procedure entailed increasing the pH of the solutions to intermediate levels (2.7, 3.0, and 3.5) and maintaining each level for ten minutes before continuing. The pH of these solutions was finally increased to either 5.3 or 5.5. Upon reaching the desired final pH level, solutions were stirred for 30 minutes and allowed to settle for an hour. Supernatants were removed with a plastic syringe and filtered through a 0.1-micron membrane filter disk. The filtrates were stabilized with nitric acid and submitted for arsenic analysis by GFAA.

The total arsenic content in the filtrates from the initial eight tests ranged from 960 to 330 ppb. Analysis of the feed indicated approximately 150 ppm total arsenic. Maximum arsenic removal was obtained with a solution treated at the high ferrous (6.5 times weight of initial arsenic) and high peroxide concentrations (4 times stoichiometric based on oxidation of all arsenic from  $As^{+3}$  to  $As^{+5}$  and oxidation of ferrous to ferric iron). This solution was oxidized for 40 minutes prior to multistage coprecipitation to pH 5.5.

The relative importance of each variable is identified in the "effect" row of Table 6. The effects are interpreted as a measure of the change in arsenic concentration caused by a unit increase in the

Table 6. Testing Conditions and Results for the Evaluation of Fenton's Reagent to Remove Arsenic from Contaminated Groundwater

Variables and Test Conditions									Test Results		
Test	H <sub>2</sub> O <sub>2</sub>	Fe <sup>2+</sup>	Reaction pH	Reaction Time, Min.	Order of Addition	Precipitation	Final Precipitate pH	Sample Size	Arsenic in Filtrate, ppm	Reagent Consumption, g	
										Ferrous	45% H <sub>2</sub> O <sub>2</sub>
Baseline	3 x Stoich.	5.0 x Wgt As	2.4	30			5.4				
Unit	1 x Stoich.	1.5 x Wgt As	0.1	10			0.1				
High Level	4 x Stoich.	6.5 x Wgt As	2.5	40	Fe First	Multi-stage	5.5				
Low Level	2 x Stoich.	3.5 x Wgt As	2.3	20	H <sub>2</sub> O <sub>2</sub> First	Single Stage	5.3				
Initial Screening Tests											
2136-10-6	2 x Stoich.	3.5 x Wgt As	2.5	20	Fe First	Multi-stage	5.3	500	0.96	0.263	1.01
2138-10-8	4 x Stoich.	3.5 x Wgt As	2.3	20	H <sub>2</sub> O <sub>2</sub> First	Multi-stage	5.5	500	0.68	0.263	2.03
2136-10-7	2 x Stoich.	6.5 x Wgt As	2.3	20	Fe First	Single Stage	5.5	500	0.48	0.488	1.62
2136-10-5	4 x Stoich.	6.5 x Wgt As	2.5	20	H <sub>2</sub> O <sub>2</sub> First	Single Stage	5.3	500	0.34	0.488	3.24
2136-10-1	2 x Stoich.	3.5 x Wgt As	2.5	40	H <sub>2</sub> O <sub>2</sub> First	Single Stage	5.5	500	0.63	0.263	1.01
2136-10-2	4 x Stoich.	3.5 x Wgt As	2.3	40	Fe First	Single Stage	5.3	50	0.57	0.488	2.03
2136-10-4	2 x Stoich.	6.5 x Wgt As	2.3	40	H <sub>2</sub> O <sub>2</sub> First	Multi-stage	5.3	500	0.36	0.488	1.62
2136-10-3	4 x Stoich.	6.5 x Wgt As	2.5	40	Fe First	Multi-stage	5.5	500	0.33	0.488	3.24
Effect	-0.06	-0.17	0.02	-0.07			-0.01				
Effect x Unit	-0.06	-0.26	0.002	-0.7			-0.001				
Change	0.6	2.6	-0.02	7	H <sub>2</sub> O <sub>2</sub> First	Single Stage	0.01				
Optimization Tests											
2136-14-1	3.6	7.6	2.38	47	H <sub>2</sub> O <sub>2</sub> First	Single Stage	5.41	500	0.35	0.57	3.32
2136-14-2	4.2	10.2	2.36	54	H <sub>2</sub> O <sub>2</sub> First	Single Stage	5.42	500	0.26	0.77	4.98
2136-14-3	4.8	12.8	2.34	61	H <sub>2</sub> O <sub>2</sub> First	Single Stage	5.43	500	0.19	0.96	6.96
2136-14-4	5.4	15.4	2.32	68	H <sub>2</sub> O <sub>2</sub> First	Single Stage	5.44	500	0.17	1.16	9.25

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associated variable. Thus, an increase in concentration of ferrous ion by one unit (1.5 times weight arsenic) decreased the arsenic concentration in the filtrate by 0.170 ppm.

Iron concentration, peroxide concentration, and reaction time were identified as the most influential variables for reducing arsenic in the filtrate. Two variables developed slight trends: reaction pH and final precipitation pH. A slight trend towards increased arsenic removal was indicated at lower reaction pH and increased precipitation pH. Slightly increased arsenic removal was also indicated with a single-stage precipitation process and peroxide-first order of addition.

An additional set of four tests was conducted to optimize conditions based on trends identified in the initial tests. Filtrate arsenic levels from these tests ranged from 350 to 170 ppb, with decreased arsenic concentration at each sequential increase of reagents and reaction time. Maximum arsenic removal (170 ppb in filtrate) was obtained at reagent concentrations of 2.3 g/l  $\text{Fe}^{2+}$  (15.4 times weight initial arsenic) and 8.3 g hydrogen peroxide per liter (5.4 times stoichiometric).

#### **NONOXIDATIVE FERRIC COPRECIPITATION**

A nonoxidative ferric iron precipitation process was evaluated in Beaker Test 2136-16. In this test, the pH of a 500-g sample of arsenic-bearing groundwater was adjusted to 2.0 and treated with 0.75 g of ferric iron. The solution pH was then increased to 5.5 with dilute NaOH and stirred for 30 minutes. The supernatant was filtered through a 0.1-micron membrane filter disk. Analysis of the filtrate indicated 290 ppb arsenic.

#### **TCLP AND ORGANIC CARBON RESULTS**

The leachability of precipitated solids from the final three Fenton's reagent tests described above was evaluated in by a modified TCLP procedure. The solids were dried at 100°C and crushed to minus 10 millimeters. Analysis of the leach liquor indicated 1.1 ppm arsenic. A similar test with precipitated solids from a ferric precipitation test (no oxidation) resulted in a leach liquor containing 0.7 ppm arsenic. The arsenic levels in the TCLP extracts were well below the EPA limit of 5 ppm.

The organic carbon content of precipitated solids from Fenton's and ferric coprecipitation procedures was determined by the Leco analytical method. Both samples were precipitated at ten-to-one iron-to-arsenic ratios. The samples were air dried overnight prior to analysis. The results from these tests showed that the precipitated solids from a Fenton's reagent treatment contained 0.49% carbon, while the ferric precipitated solids had 0.87% carbon. The reduced carbon content of the Fenton's precipitate indicated

that the oxidation process removed approximately 50% of the organic material in the groundwater sample.

#### **EFFECT OF PRECIPITATION pH ON FINAL ARSENIC LEVELS**

A set of tests was conducted to evaluate the effect of increasing precipitation pH on arsenic removal. In the initial series of tests, the pH levels of three 500-g aliquots of arsenic-bearing groundwater were adjusted to 2.0. The samples were then treated with 0.75 g of ferric ion (ten times weight of arsenic in solution). After stirring for ten minutes, the pH levels of the three test solutions were adjusted to either 5.5, 6.0, or 6.5 with NaOH. The resulting precipitates were agitated for 30 minutes and allowed to settle. The supernatant was filtered through 0.1-micron membrane filters, and the arsenic content of the resulting filtrates was determined by GFAA. The results of these tests are summarized in Table 7.

**Table 7. Effect of Precipitation pH on Arsenic Levels  
after Ferric Iron Coprecipitation**

<b>Precipitation pH</b>	<b>Arsenic Concentration, ppb</b>
<b>5.5</b>	<b>290</b>
<b>6.0</b>	<b>260</b>
<b>6.5</b>	<b>600</b>

The results from these tests showed maximum removal of arsenic at a pH level of 6.0.

In a second series of tests, three precipitation pH levels were evaluated on groundwater treated with Fenton's reagent solution. These tests were conducted on the precipitated solids from the first test of the Fenton's reagent optimization series, Test 2136-14-1. A 500-g sample of water was treated with 0.57 g ferrous iron and 1.49 g peroxide. The treated solution was first precipitated at pH 5.4 with NaOH. After agitating the precipitate slurry for ten minutes, a sample was removed, and the pH of the remaining slurry was increased to 6.0 to 6.5. Samples were removed after each adjustment. Samples were filtered through a 0.1-micron membrane filter, and the filtrates were analyzed for arsenic by GFAA. The results of these tests are given in Table 8.



**Table 8. Effect of Precipitation pH on Arsenic Levels after Fenton's Reagent Oxidation and Iron Coprecipitation**

Precipitation pH	Arsenic Concentration, ppb
5.4	350
6.0	250
6.5	540

Once again, maximum arsenic removal was obtained at pH 6.0, although little advantage was observed for using Fenton's reagent as compared to ferric iron addition in these tests. Increased arsenic removal can be expected at pH 6 with Fenton's reagent at increased ferrous iron and peroxide concentrations.

#### **SECOND-STAGE PRECIPITATION TREATMENT**

In the final group of tests, second-stage precipitation processes were evaluated. For these tests, primary filtrate from a Fenton's reagent test (150 ppb arsenic) was treated with either ferric iron or Fenton-type reagent.

In the second-stage ferric iron coprecipitation procedure, a 225-g sample of primary filtrate (pH adjusted to 2.0) was treated with 2 g of ferric iron (100 g of 20 g/l  $\text{Fe}^{3+}$ ). The pH of the resulting slurry was increased to 5.5 with NaOH, and the slurry was stirred for 30 minutes. Resulting supernatant was filtered through a 0.1-micron membrane filter. The filtrate contained 120 ppb arsenic.

In the second-stage Fenton's reagent test, the pH of a 225-g sample of primary filtrate was adjusted to 2.5 and treated with 0.6 g of ferrous iron and 4.8 g of 45% hydrogen peroxide. After one hour, the pH of the solution was increased to 5.5, and the resulting supernatant was filtered through a 0.1-micron membrane filter. Analysis of the filtrate indicated 110 ppb arsenic in the filtrate.

These results indicated only slight reduction in arsenic concentrations with both ferric and Fenton's type second-stage coprecipitation processes.

## ACTIVATED CARBON TREATMENT

A 20-g sample of filtrate from the Fenton's reagent second-stage process simulation (110 ppb) was treated with 1 g of activated carbon. The solution was stirred for five minutes and filtered through a 0.1-micron filter. Analysis of the filtrate indicated a 50 ppb arsenic, a reduction of 60 ppb.

A second activated carbon test was conducted on filtrate from a single-stage Fenton's reagent test. For this test, a 500-g sample of arsenic-bearing groundwater was treated with high levels of Fenton's reagent constituents (1.16 g ferrous iron, 4.16 g hydrogen peroxide) at a reaction pH of 3.5. After one hour, the pH of the solution was increased to 6.0 with NaOH, and the supernatant was filtered through a 0.1-micron filter. Analysis of the filtrate indicated 210 ppm arsenic. After treating a 20-g sample of filtrate with 2 g of activated carbon for one hour, the arsenic content was reduced to 170 ppm.

In a final series of activated carbon beaker tests, filtrates from single-stage Fenton's reagent and ferric iron precipitation tests were treated with 10 weight percent activated carbon. For the Fenton's evaluation, a 500-g sample of arsenic-bearing groundwater was treated with 1.16 g ferrous iron and 4.16 g hydrogen peroxide at a pH of 2.5. After agitation for one hour, the pH of the solution was increased to 6.0 with NaOH. Analysis of the resulting supernatant (0.1-micron filtrate) indicated an arsenic content of 170 ppb. After treating a 20-g sample of the filtrate with 2 g of activated carbon for one hour, the arsenic content of the filtrate was reduced to 100 ppm.

In the ferric iron coprecipitation test, a 500-g sample of groundwater was treated with 1.2 g of ferric iron at pH 2.0. The pH of the solution was then increased to 6.0. Analysis of the resulting filtrate indicated 630 ppb arsenic. After treatment with activated carbon, the arsenic concentration was reduced to 510 ppb.

The results from this series of tests indicate that activated carbon reduces the amount of arsenic of an iron coprecipitate filtrate by 60 to 120 ppb. Optimum arsenic removal was achieved with a two-stage Fenton's reaction, followed by activated carbon, to produce a filtrate containing 50 ppb arsenic.

The implication of the additional arsenic removal with activated carbon is that a refractory organic-arsenic compound is present which is resistant to destruction with Fenton's reagent. Indeed, a semiquantitative screening procedure to detect the presence of inorganic arsenic using mercury (II) bromide test paper indicated no inorganic arsenic in the filtrate from a single-stage Fenton's oxidation of the groundwater. GFAA analysis of the same filtrate revealed 170 ppb total arsenic. Characterization of the refractory organic compound, may be the key to determining the most effective treatment.

## OZONE AND ULTRAVIOLET OXIDATION TESTS

A set of two tests was conducted to evaluate the use of ozone ( $O_3$ ) as a potential treatment to destroy organic-arsenic compounds in contaminated water from the subject account. Two 500-g samples of arsenic-bearing water were treated with 15 ml  $O_3$  per minute (atmospheric pressure) for one hour. One sample was pH adjusted to 3.0 prior to treatment, while the other was treated with an unadjusted pH of 8.3. After ozonation, the sample pH levels were adjusted to 2.0, and each sample was treated with 1.6 g of ferric iron. The samples were coprecipitated at pH 6.0 with the addition of NaOH, and the resulting supernatant filtered through 0.1-micron membrane filters. Analysis of the filtrates indicated that the liquor treated at pH 8.3 produced a final arsenic concentration of 120 ppb; the sample treated at pH 3.0 had an arsenic level of 290 ppb. These are the best results achieved so far in a single-stage process and suggest that the ozone has attacked the refractory organic-arsenic compounds.

To further demonstrate the use of ozone for destruction of organic-arsenic compounds, two 150-ml samples of DMAA (1 ppm total arsenic) were treated for one hour with a 500-ml per minute gas stream containing 3% ozone. The amount of inorganic arsenic in the treated solutions was determined by the Gutzeit analytical method. These tests were conducted at pH 4 and 8, and no inorganic arsenic was produced in either sample. These results contradict data from the initial ozone/precipitation tests described above.

A third test was conducted on a 1 ppm DMAA sample that was treated with ozone and UV radiation. In this test, a four-watt UV lamp (254 nanometers) was placed in the solution during ozone sparging. Analysis of the treated solution indicated approximately 80% conversion of DMAA to inorganic arsenic in one hour.

In the final test of this series, a 150-g sample of filtrate from a first-stage ferric coprecipitation process (990 ppb) was treated with ozone (500 ml per minute of 3%  $O_3$ ) and UV radiation for one hour. The resulting solution was treated with ferric iron (20 ppm) and coprecipitated at pH 6.0. Analysis of the resulting filtrate indicated 230 ppb arsenic.

**PHASE 2**  
**Development of Oxidative and Nonoxidative**  
**Ferric Coprecipitation Processes**

**OVERVIEW**

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This phase focused on coprecipitation processes and the development of a treatment process treatment train schematic. During the initial phase of the project, a 55-gallon drum of groundwater from Monitoring Well No. 22 was shipped to Hazen Research, Inc. for testing. Analysis of the water indicated a total arsenic content of around 150 parts per million (ppm). Additional arsenic speciation studies of site groundwater conducted by the SPEAG indicated that perhaps as much as 75 percent of the arsenic was present as methylated-organic compounds.

During the initial phase of this project, it was demonstrated that the arsenic content of contaminated groundwater can be reduced from 150 ppm to 170 parts per billion (ppb) in a single-stage, oxidative process followed by coprecipitation with ferric iron. A single-stage, nonoxidative coprecipitation procedure produced a final arsenic concentration of 260 ppb. Although these coprecipitation processes provided excellent removal of inorganic arsenic species, organic-arsenicals remained in treated solutions.

A major objective of this phase of the project was to optimize conditions for a nonoxidative ferric coprecipitation process to reduce the arsenic content in groundwater to less than 200 ppb. Variables in these studies included iron-to-arsenic (Fe:As) ratio, precipitation with caustic (NaOH) or hydrated lime ( $\text{Ca}(\text{OH})_2$ ), and precipitation time. Tests were also conducted to examine the effectiveness of an oxidative ferrous iron-hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) coprecipitation process. For these tests, samples of arsenic-bearing water were treated with ferrous iron and sufficient peroxide to oxidize ferrous to ferric iron.

Additional tests were conducted to examine treatment levels for an elevated discharge limit of 2 ppm arsenic. In these tests, iron treatment levels and neutralization pH were investigated.

Preliminary process designs were prepared at the completion of laboratory confirmation tests. These include development of a general processing flowsheet for two cases: a ferric coprecipitation process capable of reducing arsenic to less than 200 ppb, and a multistage process using ozone oxidation and adsorption to reduce the arsenic concentration to less than 50 ppb.

## TEST METHODS

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Initial screening tests of proposed ferric and ferrous coprecipitation processes were performed in bench-top beaker apparatus. The amount of contaminated groundwater treated in these tests ranged from 200 to 1,800 grams (g). At the start of each experiment, an acid-rinsed glass beaker was charged with groundwater and agitated on magnetic stirplates. The pH level of the test solution was monitored with a Ag/AgCl pH electrode throughout the experiment. Iron was added as ferric sulfate or ferrous sulfate. After iron addition, each groundwater sample was agitated for approximately ten minutes, neutralized with either NaOH or  $\text{Ca}(\text{OH})_2$  to pH 6.0, and agitated for either 30 minutes or 20 hours. Upon completion of the tests, an aliquot of supernatant was filtered through a 0.45-micron membrane filter and the filtrate stabilized with ultrapure nitric acid. The filtrate arsenic level was determined by Graphite Furnace Atomic Absorption Spectroscopy (GFAA).

Large-scale, 18-kilogram (kg) tests were conducted in 7.5-gallon plastic buckets that were fitted with overhead mixers. These tests were conducted to provide sufficient solids for toxicity characteristic leaching procedure (TCLP) analysis and settling/filtration tests.

## TEST RESULTS

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### FERRIC COPRECIPITATION

A series of beaker tests was conducted to examine a nonoxidative,  $(\text{Fe}_2(\text{SO}_4)_3)$  coprecipitation process to remove arsenic from contaminated groundwater. Variables in these tests included groundwater sample, Fe:As weight ratio, precipitation with NaOH and  $\text{Ca}(\text{OH})_2$ , and precipitation time.

In the first set of ferric coprecipitation experiments, 17 beaker tests were conducted with Groundwater Sample HRI 46672. This sample was received in a plastic 55-gallon container on March 25, 1993. Since this phase of the project was conducted three to four months after receipt of the sample, it was speculated that a significant amount of inorganic arsenite in the original groundwater matrix had been oxidized to arsenate by atmospheric oxygen. Six additional tests were conducted on fresh groundwater samples (HRI 46825 and HRI 46836) to confirm process viability. The results of the fresh groundwater studies indicated that an oxidant is needed to convert arsenite to arsenate prior to addition of iron treatment.

#### Ferric Coprecipitation with Groundwater Sample HRI 46672

Seventeen beaker tests were conducted with Sample HRI 46672 to evaluate the effects of Fe:As weight ratio, precipitation with NaOH or  $\text{Ca}(\text{OH})_2$ , and precipitation time. The results from these tests are summarized in Table 9.

#### Ferric Iron:Arsenic Weight Ratio

Six 200-g groundwater tests (2136-25-1, -2, -3 and 2136-27-1, -2, -3) were conducted to establish the effect of Fe:As weight ratio on treatment efficacy. The solutions were agitated for 30 minutes after neutralization to pH 6.0.

The results from these tests indicate that increased arsenic removal was obtained at higher Fe:As weight ratios. At a 10:1 Fe:As weight ratio, supernatant arsenic levels were 360 and 251 ppb for solutions neutralized with NaOH and  $\text{Ca}(\text{OH})_2$ , respectively. At 20:1 and 30:1 iron:arsenic weight

Table 9  
 Ferric Iron Precipitation Results  
 with Groundwater Sample HRI-46671

Test ID.	Fe:As Weight Ratio	Groundwater	Weight Water	Weight Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Weight H <sub>2</sub> O <sub>2</sub> (2.4 X Stoich.)	Neutralized to pH 6.0	Precipitation Time	Initial Arsenic	Final Arsenic	% Arsenic Removed
2136-25-1	10 to 1	HRI-46672	200 g	15 g of 20 g/l Fe(III), acidified	-	5% NaOH, 15.44 g	30 minutes	150 ppm	360 ppb	99.68%
2136-25-2	20 to 1	HRI-46672	200 g	30g of 20 g/l Fe(III), acidified	-	10% NaOH, 22.00 g	30 minutes	150 ppm	149 ppb	99.88%
2136-25-3	30 to 1	HRI-46672	200 g	45 g of 20 g/l Fe(III), acidified	-	10% NaOH, 40.52 g	30 minutes	150 ppm	78 ppb	99.93%
2136-27-1	10 to 1	HRI-46672	200 g	15 g of 20 g/l Fe(III), acidified	-	Ca(OH) <sub>2</sub> , 1.25 g	30 minutes	150 ppm	251 ppb	99.82%
2136-27-2	20 to 1	HRI-46672	200 g	30g of 20 g/l Fe(III), acidified	-	Ca(OH) <sub>2</sub> , 2.68 g	30 minutes	150 ppm	93 ppb	99.93%
2136-27-3	30 to 1	HRI-46672	200 g	45 g of 20 g/l Fe(III), acidified	-	Ca(OH) <sub>2</sub> , 4.18 g	30 minutes	150 ppm	55 ppb	99.96%
2136-30-1	20 to 1	HRI-46672	200 g	30g of 20 g/l Fe(III)	-	10% NaOH, 12.25 g	30 minutes	150 ppm	98 ppb	99.92%
2136-30-2	20 to 1	HRI-46672	200 g	30g of 20 g/l Fe(III)	-	Ca(OH) <sub>2</sub> , 1.12 g	30 minutes	150 ppm	78 ppb	99.94%
2136-31-1	20 to 1	HRI-46672	200 g	30g of 20 g/l Fe(III)	-	10% NaOH, 12.57 g	30 minutes 60 minutes 120 minutes	150 ppm	118 ppb 97 ppb 99 ppb	99.90% 99.92% 99.92%
2136-31-2	20 to 1	HRI-46672	200 g	30g of 20 g/l Fe(III)	-	Ca(OH) <sub>2</sub> , 1.29 g	30 minutes 60 minutes 120 minutes	150 ppm	79 ppb 83 ppb 77 ppb	99.94% 99.94% 99.94%
2136-31-2	20 to 1	HRI-46672	200 g	30g of 20 g/l Fe(III) from FeCl <sub>3</sub>	-	Ca(OH) <sub>2</sub> , 1.53 g	30 minutes	150 ppm	90 ppb	99.93%
2136-52-1	15 to 1	HRI-46672	18 kg	201 g (Fe) <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> X11H <sub>2</sub> O in 500 ml	-	10% Ca(OH) <sub>2</sub> , 764 g	30 minutes	151 ppm	110 ppb	99.92%
2136-52-2	15 to 1	HRI-46672	18 kg	201 g (Fe) <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> X11H <sub>2</sub> O in 1 liter	-	10% Ca(OH) <sub>2</sub> , 737 g	30 minutes	151 ppm	130 ppb	99.91%
NOTE: pH of the solutions (2136-52-1 and 2136-52-2) fell to 2.04 and 2.19, respectively, after Fe(III) addition. Composite filter cake submitted for TCLP analysis.										
2136-57-1	15 to 1	HRI-46672	200 g	2.23 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> nH <sub>2</sub> O	-	10% Ca(OH) <sub>2</sub> , 9.8 g	30 minutes	150 ppm	130 ppb	99.91%
2136-57-2	15 to 1	HRI-46672	200 g	2.23 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> nH <sub>2</sub> O	-	10% Ca(OH) <sub>2</sub> , 9.4 g	30 minutes	150 ppm	70 ppb	99.93%
2136-57-3	15 to 1	HRI-46672	200 g	2.23 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> nH <sub>2</sub> O	-	10% Ca(OH) <sub>2</sub> , 9.8 g	30 minutes	150 ppm	130 ppb	99.91%
2136-59	15 to 1	HRI-46672	1.8 kg	20.1 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> nH <sub>2</sub> O	-	10% Ca(OH) <sub>2</sub> , 74.2 g	20 hours	150 ppm	69 ppb	99.95%
NOTE: Precipitated solution contained 1.11 weight percent solids. Filter cake moisture 70.3%										

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ratios, the filtrate arsenic levels dropped to 149 and 78 ppb, respectively, for the NaOH precipitation process. Supernatants from the  $\text{Ca}(\text{OH})_2$  neutralization process contained 93 and 55 ppb arsenic at respective 20:1 and 30:1 Fe:As weight ratios. Results of these tests are summarized in Figure 2.

In Tests 2136-57-1, 2136-57-2, and 2136-57-3, 200-g aliquots of groundwater were treated with solid ferric sulfate ( $\text{Fe}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$ ) at a 15:1 Fe:As weight ratio. The pH levels of the test solutions fell from 8.2 to around 2.0 upon addition of ferric sulfate. After the solution was agitated for approximately ten minutes, the pH levels test solutions were increased to 6.0 with roughly 9.6 g of a 10%  $\text{Ca}(\text{OH})_2$  slurry in deionized (DI) water. The solutions were stirred for 30 minutes, and precipitate-flocculated with a cationic polyacrylamide. Supernatants were filtered through a 0.45-micron membrane filter. Filtrates contained 130, 130, and 70 ppb arsenic.

#### **Ferric Coprecipitation with NaOH and $\text{Ca}(\text{OH})_2$**

The arsenic removal efficiencies of  $\text{Fe}_2(\text{SO}_4)_3$  coprecipitation with either NaOH or  $\text{Ca}(\text{OH})_2$  were evaluated in Tests 2136-30-1 and 2136-30-2. In these studies, 200-g aliquots of groundwater were treated with ferric iron at a 20:1 Fe:As weight ratio. Ferric sulfate was added as a 20-gram-per-liter (g/l) iron solution. The pH of the test solution fell from 8.3 to around 2.1 after iron addition. In Test 2136-30-1, the pH level of the iron-treated solution was raised to 6.0 with 12.25 g of 10% NaOH. The pH of Test 2136-30-2 was adjusted to 6.0 with 1.12 g of solid  $\text{Ca}(\text{OH})_2$ . The resulting coprecipitation slurries were agitated for 30 minutes and allowed to settle. Aliquots of supernatants were removed with a syringe and filtered through a 0.45-micron membrane filter; arsenic content was determined by GFAA. The NaOH coprecipitation process developed a supernatant arsenic concentration of 98 ppb, while 78 ppb arsenic was found in the  $\text{Ca}(\text{OH})_2$  coprecipitated filtrate. The results from these tests indicated increased arsenic removal with the  $\text{Ca}(\text{OH})_2$  coprecipitation process.

#### **Ferric Precipitation Time**

In Tests 1236-31 and 1236-32, two 200-g aliquots of groundwater sample were treated with 30 g of 20 g/l iron (from  $\text{Fe}_2(\text{SO}_4)_3$ ) and neutralized with either NaOH or  $\text{Ca}(\text{OH})_2$ . The precipitated slurries were agitated for two hours. The solutions were sampled at 30, 60, and 120 minutes after neutralization. Samples were filtered through a 0.45-micron membrane disk and the arsenic level in the filtrates determined by GFAA. A slight reduction in arsenic levels occurred at increased



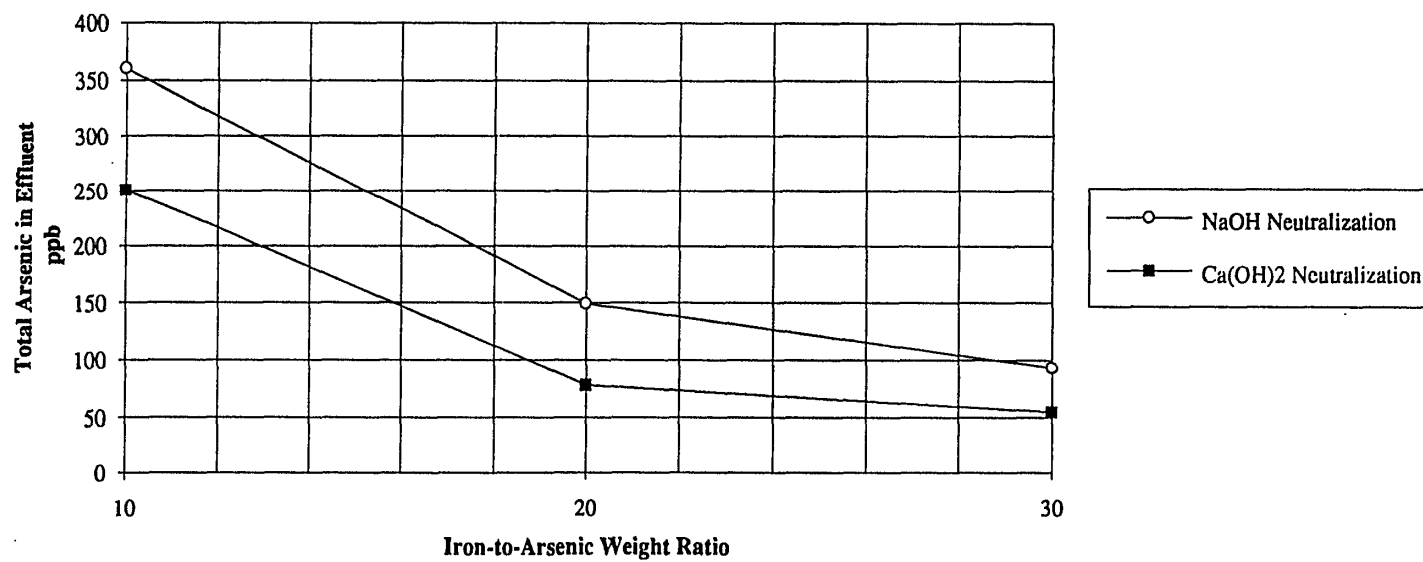


Figure 2. Dose Response Data for Ferric Coprecipitation of Arsenic with Groundwater Sample HRI-46672

precipitation times with the NaOH neutralized solutions. The increased precipitation time did not have a discernable effect on the arsenic content of filtrate from the  $\text{Ca}(\text{OH})_2$  process.

A set of experiments was performed to examine the effect of precipitation time on calcium and sulfate levels in treated supernatant. Previous studies under this project indicated precipitation of calcium sulfate in filtrate from treated solutions which were allowed to agitate for 30 minutes after neutralization. The crystalline precipitate appeared after clear filtrates were allowed to remain undisturbed overnight. In Tests 2136-57-1 and 2136-57-4, 200-g samples of groundwater were treated with ferric iron at Fe:As weight ratio of 15:1 and neutralized to pH 6.0 with solid  $\text{Ca}(\text{OH})_2$ . After neutralization, the solution in Test 2136-57-1 was allowed to agitate for 30 minutes, flocculated with a cationic polymer, and filtered through a 0.45-micron membrane. The neutralized solution in Test 2136-57-4 was agitated for 24 hours before filtration. Samples of filtrate from both tests were analyzed for calcium and sulfate content. The results of these analyses are summarized in Table 10.

**Table 10. Effect of Precipitation Time on Supernatant Calcium and Sulfate Levels**

Test No.	Precipitation Time	Calcium in Filtrate, ppm	Sulfate in Filtrate, g/l
2136-57-1	30 Minutes	1,004	2.35
2135-57-4	24 Hours	846	1.86

These results indicate that increased agitation time of neutralized coprecipitate slurries will reduce the calcium and sulfate levels in treated supernatants.

A 1.8 kg sample of groundwater was treated with 20.1 g of solid  $\text{Fe}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$  (72%  $\text{Fe}_2(\text{SO}_4)_3$ ) to produce a ferric:arsenic treatment level of 15:1 and neutralized with 74.2 g of 10 weight percent  $\text{Ca}(\text{OH})_2$  in Test 2136-59. The neutralized solution was stirred for 20 hours before the solids were flocculated with a nonionic polyacrylamide polymer. Decanted supernatant contained 69 ppb arsenic. Previous tests at 30-minute agitation times developed an average supernatant arsenic concentration of 115 ppb. From these data, it appears that increased arsenic removal can be achieved with long agitation times in neutralized solutions.

### Ferric Coprecipitation with Fresh Groundwater Samples HRI 46825 and HRI 46836

Six ferric iron coprecipitation tests were performed on two groundwater samples which were shipped overnight to Hazen in five-gallon plastic containers. All tests were conducted at 15:1 iron:arsenic weight ratios.

Sample HRI 46525 was treated in Tests 2136-49-1, 2136-49-2 and 2136-55. Head analysis of the groundwater indicated a pH of 6.9 and a total arsenic content of 141 ppm. The pH levels of the test solutions fell to approximately 2.0 after addition of ferric iron. Upon neutralization with  $\text{Ca}(\text{OH})_2$ , the coprecipitate slurries were agitated for 30 minutes. These arsenic levels in the resulting supernatants averaged around 30 ppm, far higher than in previous tests conducted under similar conditions with Sample HRI 46672. It was speculated that the increased arsenic levels of treated water were a result of a substantial amount of arsenite in the fresh groundwater feed.

In Test 2136-58-1, an excess of peroxide (1 g 50%  $\text{H}_2\text{O}_2$ ) was added to a 200-g aliquot of Sample HRI 46825 to oxidize arsenite to arsenate prior to iron addition. No change in solution pH was noted upon addition of  $\text{H}_2\text{O}_2$ . After addition of solid  $\text{Fe}_2(\text{SO}_4)_3$ , the pH level of the test solution was reduced from 6.6 to 1.9. The treated solution was then aggressively stirred for about ten minutes and neutralized to pH 6.0 with 9.6 g of a 10%  $\text{Ca}(\text{OH})_2$  slurry. The neutralized solution was agitated for 30 minutes. A control test without peroxide, 2136-58-2, was also conducted concurrently. Supernatant from the peroxide-treated solution contained 210 ppb arsenic. The control solution developed a treated arsenic level of 17 ppm.

Sample HRI 46836 was sent to Hazen for organic speciation of groundwater feed and treated solutions. In Test 2136-63-1, a 7 kg split of the groundwater was transferred to a five-gallon plastic bucket and treated with 0.75 g of 50%  $\text{H}_2\text{O}_2$  (sufficient peroxide to oxidize arsenite to arsenate, assuming 150 ppm total arsenic and 50 ppm arsenite). After  $\text{H}_2\text{O}_2$  addition, the solution was treated with solid  $\text{Fe}_2(\text{SO}_4)_3$ . The solution pH was reduced from 6.6 to 2.2 after addition of the ferric treatment. The solution was stirred for ten minutes and neutralized to pH 6.0 with 265 g of 10 weight percent solution of  $\text{Ca}(\text{OH})_2$ . The neutralized solution was agitated for 20 hours with an overhead mixer. Analysis of the groundwater feed and treated solution indicated arsenic levels of 102 ppm and 32 ppb, respectively.

A summary of test results is presented in Table 11. These results indicate that in order to obtain an effluent arsenic level of less than 200 ppb from unoxidized groundwater, an oxidizing agent (peroxide, chlorine, or ozone) should be added to the feed solution prior to iron addition.

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Table 11

Precipitation Results with Fresh Groundwater  
Samples HRI-46825 and HRI-46836

Test ID.	Fe:As Weight Ratio	Groundwater	Weight Water	Weight Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Weight H <sub>2</sub> O <sub>2</sub> (2.4 X Stoich.)	Neutralized to pH 6.0	Precipitation Time	Initial Arsenic	Final Arsenic	% Arsenic Removed
2136-49-1	15 to 1	HRI-46825	500 g	56.25 g of 20 g/l Fe(III) from FeCl <sub>3</sub>	-	Ca(OH) <sub>2</sub> , 3.05 g	30 minutes	141 ppm	38 ppm	70.21%
2136-49-2	15 to 1	HRI-46825	500 g	56.25 g of 20 g/l Fe(III)	-	Ca(OH) <sub>2</sub> , 5.0 g	30 minutes	141 ppm	35 ppm	72.34%
2136-55	15 to 1	HRI-46825	200 g	2.23 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> -nH <sub>2</sub> O in 30 ml	-	10% Ca(OH) <sub>2</sub> , 22.5 g	30 minutes	141 ppm	26 ppm	76.60%
2136-58-1	15 to 1	HRI-46825	200 g	2.23 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> -nH <sub>2</sub> O	50% H <sub>2</sub> O <sub>2</sub> , 1.0 g	10% Ca(OH) <sub>2</sub> , 9.6 g	30 minutes	141 ppm	210 ppb	99.84%
2136-58-2	15 to 1	HRI-46825	200 g	2.23 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> -nH <sub>2</sub> O	-	10% Ca(OH) <sub>2</sub> , 9.6 g	30 minutes	141 ppm	17 ppm	87.23%
2136-63-1	15 to 1	HRI-46836	7 kg	78.17 g Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> -nH <sub>2</sub> O	50% H <sub>2</sub> O <sub>2</sub> , 0.749 g	10% Ca(OH) <sub>2</sub> , 265 g	20 Hours	102 ppm	32 ppb	99.97%
Test ID.	Fe:As Weight Ratio	Groundwater	Weight Water	Weight FeSO <sub>4</sub>	Weight H <sub>2</sub> O <sub>2</sub> (1.2 X Stoich.)	Neutralized to pH 6.0	Precipitation Time	Initial Arsenic	Final Arsenic	% Arsenic Removed
2136-48-1	20 to 1	HRI-46825	500 g	30 g of 50 g/l Fe(II)	50% H <sub>2</sub> O <sub>2</sub> , 2.20 g	Ca(OH) <sub>2</sub> , 1.59 g	30 minutes	141 ppm	73 ppb	99.94%
2136-48-2	15 to 1	HRI-46825	500 g	22.5 g of 50 g/l Fe(II)	50% H <sub>2</sub> O <sub>2</sub> , 1.65 g	Ca(OH) <sub>2</sub> , 1.13 g	30 minutes	141 ppm	110 ppb	99.92%

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## OXIDATIVE FERROUS SULFATE COPRECIPITATION

The effectiveness of an oxidative ferrous-iron coprecipitation procedure to remove arsenic was evaluated in a series of 19 bench-top beaker tests. Initial tests were conducted on Sample HRI 46672. Two confirmatory tests were performed on fresh Sample HRI 46825.

### Oxidative Ferrous Sulfate Coprecipitation with Groundwater Sample HRI 46672

Aliquots of Sample HRI 46672 were treated with ferrous sulfate at Fe:As weight ratios ranging from 10:1 to 30:1. After iron addition, the solutions were treated with hydrogen peroxide at 2.4 times the stoichiometric amount required to oxidize ferrous to ferric iron (assume one mole of  $H_2O_2$  to oxidize one mole of ferrous to ferric iron). Solutions were then stirred for approximately ten minutes and neutralized to pH 6.0 with either NaOH or  $Ca(OH)_2$ . Three test variables were evaluated: iron:arsenic weight ratio, neutralization with NaOH or  $Ca(OH)_2$ , and precipitation time of 30 minutes or 20 hours. The results from these tests are summarized in Table 12.

#### Iron:Arsenic Weight Ratio

Initial screening tests were conducted at Fe:As weight ratios of 10:1, 20:1 and 30:1. These experiments were performed on 200-g aliquots of groundwater with 30 minutes agitation after neutralization with either NaOH or  $Ca(OH)_2$ . The results were similar to the ferric screening tests, with increased arsenic removal noted at higher ferrous:arsenic weight ratios. At 10:1 and 20:1 ferrous:arsenic treatment levels, the NaOH neutralized solution contained 210 and 91 ppb arsenic. Solutions neutralized with  $Ca(OH)_2$  produced treated liquors with arsenic concentrations of 393 and 61 ppb.

The variability of test results was examined in a series of three 200-g tests (2136-38-1, -2, -3) which were performed at Fe:As weight ratios of 15:1. During the tests, the pH levels of the groundwater were reduced from 8.2 to 3.0 after addition of ferrous iron. The pH levels were further reduced to around 2.5 after oxidation with peroxide. The solutions were stirred for ten minutes and neutralized to pH 6.0 with approximately 0.67-g solid  $Ca(OH)_2$ . Neutralized slurries were agitated for 30 minutes and flocculated with a cationic polymer. Filtered supernatant contained 95, 93, and 82 ppb arsenic.

Table 12

**Ferrous Iron/Hydrogen Peroxide Precipitation Results  
with Groundwater Sample HRI-46672**

Test ID.	Fe:As Weight Ratio	Groundwater	Weight Water	Weight FeSO <sub>4</sub>	Weight H <sub>2</sub> O <sub>2</sub> (2.4 X Stoich.)	Neutralized to pH 6.0	Precipitation Time	Initial Arsenic	Final Arsenic	% Arsenic Removed
2136-28-1	10 to 1	HRI-46672	200 g	6g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 0.645 g	5% NaOH, 6.48 g	30 minutes	150 ppm	210 ppb	99.85%
2136-28-2	20 to 1	HRI-46672	200 g	12 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.29 g	10% NaOH, 9.02 g	30 minutes	150 ppm	91 ppb	99.93%
2136-29-1	30 to 1	HRI-46672	200 g	18 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.94 g	10% NaOH, 13.23 g	30 minutes	150 ppm	69 ppb	99.95%
2136-29-2	10 to 1	HRI-46672	200 g	6g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 0.645 g	Ca(OH) <sub>2</sub> , 0.42 g	30 minutes	150 ppm	393 ppb	99.73%
2136-29-3	20 to 1	HRI-46672	200 g	12 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.29 g	Ca(OH) <sub>2</sub> , 0.85 g	30 minutes	150 ppm	61 ppb	99.96%
2136-30-3	20 to 1	HRI-46672	200 g	12 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.29 g	10% NaOH, 6.28 g	30 minutes	150 ppm	82 ppb	99.94%
2136-30-4	20 to 1	HRI-46672	200 g	12 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.29 g	Ca(OH) <sub>2</sub> , 0.59 g	30 minutes	150 ppm	106 ppb	99.92%
2136-37	20 to 1	HRI-46672	18 kg	269 g FeSO <sub>4</sub> (7H <sub>2</sub> O) in 1 Liter DI	50 % H <sub>2</sub> O <sub>2</sub> , 82 g	Ca(OH) <sub>2</sub> , 62.8 g	30 minutes	148 ppm	75 ppb	99.95%
NOTE: pH of the solution fell to 3.19 after Fe(II) addition, pH fell to 2.71 after H <sub>2</sub> O <sub>2</sub> addition. Filter cake submitted for TCLP analysis										
2136-38-1	15 to 1	HRI-46672	200 g	9 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 0.968 g	Ca(OH) <sub>2</sub> , 0.69 g	30 minutes	150 ppm	95 ppb	99.93%
2136-38-2	15 to 1	HRI-46672	200 g	9 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 0.97 g	Ca(OH) <sub>2</sub> , 0.61 g	30 minutes	150 ppm	93 ppb	99.93%
2136-38-3	15 to 1	HRI-46672	200 g	9 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 0.98 g	Ca(OH) <sub>2</sub> , 0.70 g	30 minutes	150 ppm	82 ppb	99.94%
2136-39-1	20 to 1	HRI-46672	200 g	12 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.29 g	Ca(OH) <sub>2</sub> , 0.96 g	30 minutes	150 ppm	208 ppb	99.85%
2136-39-2	20 to 1	HRI-46672	200 g	12 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.29 g	Ca(OH) <sub>2</sub> , 0.71 g	30 minutes	150 ppm	85 ppb	99.94%
2136-39-2	20 to 1	HRI-46672	200 g	12 g of 50 g/l Fe(II)	34% H <sub>2</sub> O <sub>2</sub> , 1.29 g	Ca(OH) <sub>2</sub> , 0.75 g	30 minutes	150 ppm	98 ppb	99.93%
2136-47	15 to 1	HRI-46672	18 kg	200 g FeSO <sub>4</sub> (7H <sub>2</sub> O) in 1 Liter DI	50 % H <sub>2</sub> O <sub>2</sub> , 62 g	Ca(OH) <sub>2</sub> , 47.1 g	30 minutes	159 ppm	111 ppb	99.93%
NOTE: pH of the solution fell to 6.71 after Fe(II) addition, pH fell to 2.78 after H <sub>2</sub> O <sub>2</sub> addition. Filter cake submitted for TCLP analysis										
2136-53-1	15 to 1	HRI 46672	18 kg	203 g FeSO <sub>4</sub> (7H <sub>2</sub> O) in 1 Liter DI	50 % H <sub>2</sub> O <sub>2</sub> , 61.5 g	10% Ca(OH) <sub>2</sub> , 484 g	30 minutes	150 ppm	100 ppb	99.93%
2136-60	15 to 1	HRI-46672	1.8 kg	203 g FeSO <sub>4</sub> (7H <sub>2</sub> O)	50 % H <sub>2</sub> O <sub>2</sub> , 6.15 g	10% Ca(OH) <sub>2</sub> , 50.1 g	20 hours	150 ppm	68 ppb	99.95%
NOTE: Precipitated solution contained 0.69 weight percent solids. Filter cake moisture 73%										

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### **Oxidative Ferrous Sulfate Coprecipitation with Caustic and Hydrated Lime**

The effect of neutralizing reagent (NaOH or  $\text{Ca}(\text{OH})_2$ ) on treatment efficiency was investigated in Tests 2136-30-1 and 2136-30-2. The results of these tests indicated that the NaOH neutralization process provided superior removal of arsenic from the contaminated groundwater. The NaOH-neutralized supernatant contained 82 ppb arsenic, while 106 ppb was found in the  $\text{Ca}(\text{OH})_2$  filtrate. Since these results contradict trends identified in previous tests, in which greater arsenic removal was obtained with the  $\text{Ca}(\text{OH})_2$  neutralization process, additional testing should be considered to verify the efficacy of neutralization procedures with the ferrous coprecipitation process.

### **Precipitation Time**

A single test was performed to estimate the effect of precipitation time on arsenic removal. In Test 2136-60, a 1.8 kg sample of groundwater was treated with 203 g of  $\text{FeSO}_4(7\text{H}_2\text{O})$ , 6.15 g of 50% hydrogen peroxide, and 5.01 g of  $\text{Ca}(\text{OH})_2$ ; the neutralized slurry was agitated for 20 hours with an overhead mixer. The resulting supernatant contained 68 ppb arsenic. Similar tests with 30-minute agitation averaged 90 ppb arsenic in the treated liquor.

### **Oxidative Ferrous Sulfate Coprecipitation with Fresh Groundwater Sample HRI 46825**

Two ferrous coprecipitation tests were conducted with a fresh groundwater sample, HRI 46825. Tests were performed at ferrous:arsenic ratios of 15:1 (2136-48-2) and 20:1 (2136-48-1). The pH levels of the groundwater fell from 6.8 to around 6.4 following addition of ferrous iron. After treatment with  $\text{H}_2\text{O}_2$ , the pH levels were further reduced to approximately 2.5 from hydrolysis of ferric iron. The solutions were neutralized with  $\text{Ca}(\text{OH})_2$  and agitated for 30 minutes. The treated solution from the study which used a 15:1 Fe:As weight ratio contained 110 ppb arsenic. The process using a 20:1 weight ratio produced a final liquor with an arsenic concentration of 73 ppb. The results of these studies are summarized in Table 11.

### **Oxidative Ferrous Sulfate Coprecipitation with Water Spiked with One Gram Arsenic per Liter from Cacodylic Acid**

In Tests 2136-40 and 2136-41, two 500-g aliquots of groundwater HRI 46672 were spiked with 1 g/l arsenic from cacodylic acid (dimethylarsenic acid). The waters were treated with ferrous sulfate at 15:1 and 20:1 iron:arsenic ratios. After oxidation with  $\text{H}_2\text{O}_2$  and neutralization with  $\text{Ca}(\text{OH})_2$ , the 15:1 ratio produced a final filtrate containing 1.88 ppm arsenic. The treatment using a 20:1 ratio developed 1.09 ppm arsenic in the treated solution. The filter cakes from these two tests were



combined and submitted for TCLP analysis. The results of TCLP analysis, Table 13, indicated that the filter cake solids produced 45.6 ppm arsenic in the test leachate, far above the 5 ppm limit. Further testing should be considered to evaluate actual groundwaters with high arsenic levels.

#### **FILTER CAKE TCLP RESULTS**

Four large-scale, 18 kg tests were performed on Sample HRI 46672 to provide sufficient solid for flocculation and filtration testing. The filter cakes from the two ferric coprecipitation tests were combined into a composite sample. The filter cakes were dried at 100°C for 18 hours and the residue subjected to the TCLP analytical procedure. The results of the leaching tests are summarized in Table 13. All of the filter cakes passed the TCLP protocol.

#### **WATER ANALYSIS OF GROUNDWATER FEED AND SELECTED TREATED SOLUTIONS**

Table 14 summarizes analyses of Samples HRI 46672 and HRI 46825 and selected filtrates from ferric and ferrous precipitation processes.

#### **SECONDARY/TERTIARY TREATMENT PROCESSES**

A series of tests was conducted to determine if activated carbon adsorption or ozone oxidation processes effectively reduce the arsenic levels in supernatants from the ferrous and ferric coprecipitation processes. The results from these tests were used to define a treatment process to reduce the effluent arsenic concentration in treated water to less than 50 ppb.

##### **Activated Carbon Treatment**

The effectiveness of activated carbon in the removal of trace quantities of arsenic was determined in a series of nine stirred beaker tests. Filtrates from ferrous and ferric coprecipitation processes were mixed with activated carbon on a magnetic stirplate. All tests were conducted at a 20 weight percent carbon pulp density. The results of these tests are presented in Table 15.

Table 13

## TCLP Results of Precipitate Filter Cakes

Test I.D.	Ferrous Iron Precipitation			Ferric Iron Precipitation	TCLP Limit
	<u>2136-37</u>	<u>2136-47</u>	<u>2136-40.41</u>	<u>2136-52-1.2</u>	
Iron: Arsenic Weight Ratio	20 to 1	15 to 1	Comp. 20 to 1 and 15 to 1	Comp. to 15:1	
Water Sample	HRI-46672	HRI-46672	HRI-46672 Spiked with 1 g/l Cacodylic Acid (as As)	HRI-46672	
Precipitation Time, hours	0.5	0.5	0.5	20	
TCLP Analysis of Dried Filter Cake					
As, ppm	0.224	0.298	45.6	1.6	5
Ba, ppm	0.16	0.10	0.14	0.16	100.00
Cd, ppm	<0.02	<0.02	<0.02	<0.025	1
Cr, ppm	<0.05	<0.05	<0.05	<0.05	5
Pb, ppm	<0.1	<0.1	<0.1	<0.1	5
Hg, ppm	<0.0002	<0.0002	<0.0002	<0.0002	0.2
Se, ppm	<0.01	<0.01	<0.01	<0.01	1
Ag, ppm	<0.05	<0.05	<0.05	<0.05	5
Arsenic in Filtrate	0.075 ppm	0.111 ppm	20:1 Fe:As Filtrate: 1.09 ppm 15:1 Fe:As Filtrate: 1.88 ppm	2136-52-1: 0.110 ppm 2136-52-2: 0.130 ppm	

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Table 14

## Water Analysis of Filtrates from Iron Coprecipitation Processes

Test I.D.	Ferrous Iron Precipitation							Ferric Iron Precipitation	
	2136-37	2136-37	2136-47	2136-47	2136-48-2	2136-48-2	2136-60	2136-56	2136-59
Iron:Arseenic Weight Ratio	20:1 Head	20:1 Filtrate	15:1 Head	15:1 Filtrate	15:1 Head	15:1 Filtrate	15:1 Filtrate	15:1 Filtrate	15:1 Filtrate
Water Sample	HRI-46672	HRI-46672	HRI-46672	HRI-46672	HRI-46825	HRI-46825	HRI-46672	HRI-46672	HRI-46672
Precipitation Time, hours		0.5		0.5		0.5	20	20	20
Cation Analysis									
Calcium, ppm	433	1,730	417	1230	487	1580	880	860	880
Magnesium, ppm	221	203	221	216	244	231	219	233	220
Sodium, ppm	783	694	777	752	804	780	731	918	711
Nickel, ppm	0.10	0.22	0.08	0.20	0.10	0.24	0.20	0.36	0.30
Cadmium, ppm	<0.02	0.02	<0.02	<0.02	<0.02	0.02	0.04	<0.02	0.04
Lead, ppm	0.10	0.28	0.14	0.28	0.16	0.26	0.36	0.18	0.34
Copper, ppm	0.12	0.14	0.08	0.12	0.08	0.14	0.06	0.04	0.06
Chromium, ppm	<0.02	0.02	<0.02	0.02	<0.02	0.02	<0.02	0.04	<0.02
Silver, ppm	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	0.10	-
Mercury, ppm	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	-	-
Selenium, ppm	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-
Iron, ppm	-	-	-	-	-	-	0.06	-	0.06
Arsenic, ppm	148	0.075	159	0.111	141	0.110	0.069	-	0.068
Anion Analysis									
Chloride, ppm	4400	4880	2020	1610	1710	1980	1880	2130	1930
Sulfate, ppm	490	4170	500	2890	550	3650	1960	1900	1910
Solids (Dissolved), ppm	6440	10200	6510	8440	7040	-	-	6720	-
TOC, ppm	23	-	23	4	24	-	-	-	-

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Table 15

**Activated Carbon Tests**  
**Solutions Treated with 20 Weight Percent Activated Carbon**

Test I.D.	Filtrate From Test	Ground Water	Fe:As Ratio	Neutralizing Agent	Initial [As] in Primary Filtrate	Resid. Time	Carbon Treated Filtrate	% Arsenic Removed
2136-26-1	2136-25-1 (Ferric)	HRI-46672	10:1	NaOH	360 ppb	1 Hour	221 ppb	39%
2136-26-2	2136-25-2 (Ferric)	HRI-46672	20:1	NaOH	149 ppb	1 Hour	76 ppb	49%
2136-26-3	2136-25-3 (Ferric)	HRI-46672	30:1	NaOH	78 ppb	1 Hour	75 ppb	4%
2136-27-1c	2136-27-1 (Ferric)	HRI-46672	10:1	Ca(OH) <sub>2</sub>	251 ppb	1 Hour	282 ppb	-12%
2136-27-2c	2136-27-1 (Ferric)	HRI-46672	20:1	Ca(OH) <sub>2</sub>	93 ppb	1 Hour	98 ppb	-5%
2136-27-3c	2136-27-1 (Ferric)	HRI-46672	30:1	Ca(OH) <sub>2</sub>	55 ppb	1 Hour	37 ppb	33%
2136-28-1c	2136-28-1 (Ferrous)	HRI-46672	10:1	NaOH	210 ppb	1 Hour	125 ppb	40%
2136-28-2c	2136-28-2 (Ferrous)	HRI-46672	20:1	NaOH	91 ppb	1 Hour	54 ppb	41%
2136-46	2136-37 (Ferrous)	HRI-46672	20:1	Ca(OH) <sub>2</sub>	69 ppb	15 minutes	44 ppb	36%
						30 minutes	35 ppb	49%
						45 minutes	23 ppb	67%
						60 minutes	22 ppb	68%
						120 minutes	16 ppb	77%
						240 minutes	20 ppb	71%

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Initial tests were conducted on 20-milliliter (ml) aliquots of filtrate and 4 to 5 g of activated carbon. Results from these tests indicated a great deal of scatter (arsenic removal ranging from 49% to minus 12%), and treatment efficacy was inconclusive.

A final test was conducted on a 800-g sample of filtrate of HRI 46672 which was treated with a 20:1 ferrous:arsenic weight ratio/ $\text{Ca}(\text{OH})_2$  program. The filtrate was treated with activated carbon for four hours. Samples of slurry were removed at 15, 30, 45, 60, 120, and 240 minutes and filtered through a 0.45-micron filter. Analysis of the filtrate indicated reductions in arsenic of 36% to 77%, resulting in final arsenic levels of 44 to 16 ppb.

### Ozone Oxidation

A single study was conducted to determine if ozone oxidation can be employed to destroy organic arsenic compounds in coprecipitation supernatants. In this test, 2136-50, 500 g of supernatant from Test 2136-47 (ferrous coprecipitation with  $\text{Ca}(\text{OH})_2$  neutralization) was treated with a two-liter-per-minute oxygen/ozone stream which contained 2% ozone. The pH level of the supernatant was adjusted to 10 prior to ozone treatment. After 30 minutes, two 200-g and one 50-g aliquots of treated supernatant were removed. The 200-g aliquots were treated with 1000 ppm and 50 ppm ferric iron and neutralized with  $\text{Ca}(\text{OH})_2$ . These slurries were stirred for 30 minutes and supernatant filtered through a 0.45-micron membrane disk. The resulting filtrates contained less than 3 ppb arsenic.

The 50-g aliquot was treated with activated alumina for 30 minutes. The filtrate from this procedure contained 1 ppb arsenic.

### COPRECIPITATE THICKENING/FILTRATION TESTS

Pocock Industrial was contracted to conduct thickening, filtration, and rheology studies on coprecipitate slurries from ferrous and ferric coprecipitation procedures. Tests were conducted at Fe:As weight ratios of 15:1, and the precipitated slurries neutralized with  $\text{Ca}(\text{OH})_2$ . Tests 2136-52-1 and 2136-52-2 produced ferric coprecipitate slurries. Ferrous/peroxide solutions were prepared in Tests 2136-37 and 2316-47. The solutions were agitated for 30 minutes after iron addition. An additional test, 2136-62, was conducted to provide total-dissolved-solid information for a ferric process with a 20-hour precipitation time. Supernatant from this test contained 5730 ppm total dissolved solids. The results from the thickening/filtration tests were used to size a clarifier and filter press for a commercial process. A copy of the test results from Pocock Industrial is provided in Appendix A.

## ORGANIC ANALYSIS

Sample HRI 46836 was shipped to Hazen for characterization of organic compounds. Total organic analyses (volatiles, semivolatiles, pesticide, PCB, BTEX) were performed on the untreated groundwater and a treated solution. A 7.5 kg split of groundwater was treated with ferric iron at a 15:1 Fe:As weight ratio. The solution was neutralized with  $\text{Ca}(\text{OH})_2$  and agitated for 20 hours.

The results of the organic analysis of the groundwater (HRI 46836) and treated solution (2136-64) are provided in Appendix B.

## FERRIC COPRECIPITATION TO ACHIEVE 2 PPM ARSENIC DISCHARGE LIMIT

A series of beaker tests was conducted to evaluate reduced iron treatment levels to produce an effluent with less than 2 ppm total arsenic. Tests were performed on the groundwater sample HRI No. 46825 (150 ppm total arsenic). The groundwater was treated at five different iron-to-arsenic weight ratios (2:1, 3:1, 5:1, 10:1, and 15:1) and neutralized with either  $\text{Ca}(\text{OH})_2$  or NaOH.

The groundwater samples were treated with three times stoichiometric hydrogen peroxide to oxidize arsenite to arsenate (assuming 50 ppm arsenite in groundwater) and solid ferric sulfate. The solution was then stirred for ten minutes and neutralized to pH 6.0 with either 10%  $\text{Ca}(\text{OH})_2$  or 5% NaOH. The resulting slurries were stirred for an additional 30 minutes and allowed to settle. Supernatants were filtered through a membrane filter, and the arsenic content of the filtrate was determined by GFAA. The results of these tests are summarized in Table 16 and Figure 3.

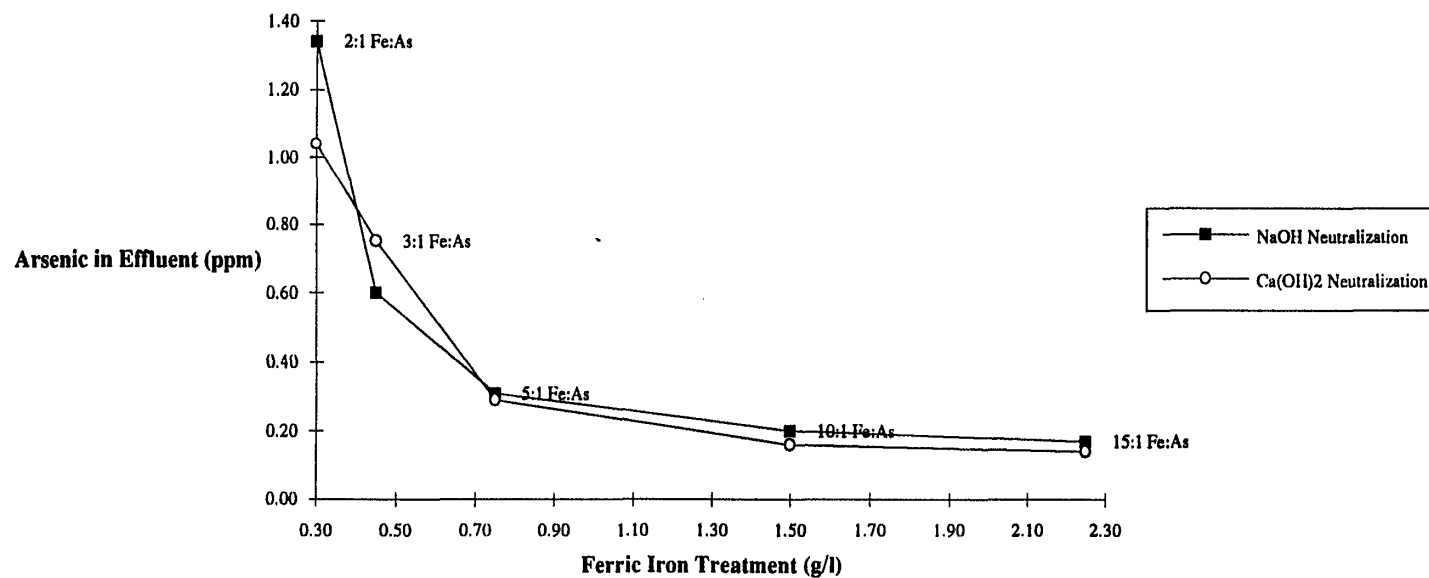
These results demonstrate that an iron treatment level as low as 2:1 iron-to-arsenic weight ratio can reduce the arsenic level in contaminated water from 150 ppm to less than 2 ppm. At this treatment level, the  $\text{Ca}(\text{OH})_2$  neutralized filtrate contained 1.04 ppm total arsenic, while NaOH neutralization produced filtrate which contained 1.34 ppm total arsenic.

**Ferric Coprecipitation Tests to Produce Effluent with < 2 ppm Arsenic  
with Groundwater HRI-46825**

Test I.D.	Fe:As Weight Ratio	Groundwater	Weight Water	Weight Fe2(SO4)3·nH2O	Weight H2O2 (3 X Stoich.)	Neutralized to pH 6.0	Precipitation Time	Initial Arsenic	Final Arsenic	% Arsenic Removed
2136-65-1	2 to 1	HRI-46825	200 g	0.298 g	0.04 mg (50% H2O2)	5% NaOH, 1.25 g	30 minutes	150 ppm	1.34 ppm	99.68%
2136-65-2	3 to 1	HRI-46825	200 g	0.448 g	0.04 mg (50% H2O2)	5% NaOH, 3.04 g	30 minutes	150 ppm	0.60 ppm	99.88%
2136-65-3	5 to 1	HRI-46825	200 g	0.745 g	0.04 mg (50% H2O2)	5% NaOH, 5.25 g	30 minutes	150 ppm	0.31 ppm	99.93%
2136-65-4	10 to 1	HRI-46825	200 g	1.491 g	0.04 mg (50% H2O2)	5% NaOH, 9.18 g	30 minutes	150 ppm	0.20 ppm	99.93%
2136-65-5	15 to 1	HRI-46825	200 g	2.237 g	0.04 mg (50% H2O2)	5% NaOH, 19.37 g	30 minutes	150 ppm	0.17 ppm	99.93%
2136-67-1	2 to 1	HRI-46825	200 g	0.298 g	0.04 mg (50% H2O2)	10% Ca(OH)2, 1.5 g	30 minutes	150 ppm	1.04 ppm	99.68%
2136-67-2	3 to 1	HRI-46825	200 g	0.448 g	0.04 mg (50% H2O2)	10% Ca(OH)2, 1.8 g	30 minutes	150 ppm	0.75 ppm	99.88%
2136-67-3	5 to 1	HRI-46825	200 g	0.745 g	0.04 mg (50% H2O2)	10% Ca(OH)2, 2.7 g	30 minutes	150 ppm	0.29 ppm	99.93%
2136-67-4	10 to 1	HRI-46825	200 g	1.49 g	0.04 mg (50% H2O2)	10% Ca(OH)2, 5.2 g	30 minutes	150 ppm	0.16 ppm	99.93%
2136-67-5	15 to 1	HRI-46825	200 g	2.237 g	0.04 mg (50% H2O2)	10% Ca(OH)2, 8.9 g	30 minutes	150 ppm	0.14 ppm	99.93%

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Dose Response Data for  
Ferric Coprecipitation of Arsenic  
Groundwater Sample HRI-46825



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### 2:1 Iron-to-Arsenic Weight Ratio Treatment Level

The effect of neutralization pH on the efficacy of the 2:1 iron-to-arsenic weight ratio treatment program was investigated in a series of six 200 g beaker tests. In these tests, solutions were neutralized to pH 5.5, 6.0, or 6.5 with  $\text{Ca}(\text{OH})_2$  after addition of the ferric sulfate treatment. The neutralized solutions were stirred for 30 minutes, settled, and supernatants filtered through 0.45-micron membrane filters. The arsenic content of the filtrates was determined by FAA. Two types of groundwaters were tested: a composite solution of fresh, unoxidized well waters (HRI No. 46825 and 46826) and the oxidized groundwater sample (HRI No. 46672). Due to the limited quantity of fresh, unoxidized well water, the composite groundwater was treated in small-scale (400 g) beaker tests. Large-scale coprecipitation tests (12 kg) were conducted on oxidized groundwater, HRI No. 46672, to provide sufficient solids for TCLP analysis.

Table 17. Effect of pH on Effluent Arsenic Levels  
(2:1 Iron-to-Arsenic Weight Ratio)

Test No.	Water Sample	Neutralization pH	Initial As, ppm	Final As, ppm
2136-68-1	46825 & 46836	5.5	111	2.78
2136-68-2	46825 & 46836	6.0	111	1.14
2136-68-3	6825 & 46836	6.5	111	4.49
2136-69-1	46672	5.5	118	2.00
2136-69-2	46672	6.0	118	1.39
2136-69-3	46672	6.5	118	3.69

These results indicate that maximum arsenic removal is obtained at a neutralization pH of 6.0.

Solids from the large-scale 2:1 iron-to-arsenic weight ratio coprecipitation studies (Tests 2136-69-1, 2136-69-2, and 2136-69-3) were collected by filtration and filter cakes submitted for TCLP analysis. The results of the TCLP analysis are summarized in Table 18.

The results show that although a 2:1 iron-to-arsenic treatment level will produce a supernatant with less than 2 ppm total arsenic, precipitated solids produce TCLP leachates with arsenic levels far above the 5 ppm regulatory limit.

**Table 18. TCLP Analysis of Filter Cakes from 2:1 Iron-to-Arsenic Weight Ratio Treatment Level with Groundwater Sample 46672**

TCLP Analyte	Neutralization pH		
	5.5	6.0	6.5
Arsenic , ppm	187	89.2	87.9
Barium, ppm	0.07	0.10	0.13
Cadmium, ppm	<0.01	<0.005	<0.005
Chromium, ppm	<0.02	<0.01	<0.01
Lead, ppm	0.11	0.03	<0.02
Mercury, ppm	0.0038	0.0061	0.0003
Selenium, ppm	0.01	<0.01	<0.01
% Solids in Filter Cake	16.8	14.8	15.3

#### 7:1 Iron-to-Arsenic Weight Ratio Treatment Level

##### Ferric Sulfate and Peroxide Oxidation

A 20 kg coprecipitation test was conducted to investigate the efficacy of the ferric coprecipitation process at a 7:1 iron-to-arsenic weight ratio. In this test, a fresh groundwater sample (HRI No. 46965-2) containing 150 ppm arsenic was treated with three times stoichiometric hydrogen peroxide required to oxidize arsenite to arsenate (assume 50 ppm arsenite) and 21 g of ferric iron. The iron was added as a solution of ferric sulfate (12 weight percent iron). After addition of the ferric treatment, the pH level of the solution dropped to 2.58. The treated water was stirred for ten minutes and neutralized to pH 6.0 with 53.52 g  $\text{Ca(OH)}_2$  (from a 10 weight percent slurry of  $\text{Ca(OH)}_2$  and tap water). The resulting slurry was stirred for 30 minutes and vacuum filtered through a large Buchner

funnel, and the filter cake was submitted for TCLP analysis. A summary of the TCLP results and filtrate analysis is provided in Table 19.

These results indicate that arsenic-contaminated groundwater from the Crystal Chemical site can be treated with hydrogen peroxide (three times stoichiometric to oxidize 50 ppm arsenite to arsenate) and ferric iron (7:1 iron-to-arsenic weight ratio) to produce solids which pass TCLP protocol and a filtered effluent with less than 2 ppm total arsenic.

**Table 19. Ferric Coprecipitation at 7:1 Iron-to-Arsenic Weight Ratio with Groundwater Sample 46965-2**

<b>TCLP Analyte</b>	<b>Concentration</b>
<b>Arsenic , ppm</b>	<b>1.69</b>
<b>Barium, ppm</b>	<b>0.18</b>
<b>Cadmium, ppm</b>	<b>0.025</b>
<b>Chromium, ppm</b>	<b>0.05</b>
<b>Lead, ppm</b>	<b>&lt;0.1</b>
<b>Mercury, ppm</b>	<b>&lt;0.0002</b>
<b>Selenium, ppm</b>	<b>&lt;0.01</b>
<b>% Solids in Filter Cake</b>	<b>23</b>
<b>Arsenic in Filtrate, ppm</b>	<b>0.41</b>

#### **Ferric Chloride and Peroxide Oxidation**

A second test at the 7:1 iron-to-arsenic weight ratio was conducted to examine the efficacy of ferric chloride as the iron source in Test 2136-72. In this study, a 20.7 kg aliquot of groundwater sample 47049-1 (166 ppm total arsenic) was transferred into a 7.5-gallon plastic bucket. The water was stirred with an overhead mixer and treated with 9.34 g of 50% hydrogen peroxide. This quantity of  $H_2O_2$  represents three times the stoichiometric amount required to oxidize arsenite to arsenate, assuming 50% of the total arsenic in the groundwater is available as arsenite. After agitation for ten hours, the pH level of the solution had increased from 6.45 to 7.93. The test solution was treated with 116.2 g of solid

$\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  to produce a 7:1 iron-to-arsenic weight ratio and stirred for 30 minutes. After addition of the iron treatment, the pH level of the water fell to 2.3. The solution was neutralized to a pH level of 6.0 with a slow addition of 41.52 g of solid  $\text{Ca}(\text{OH})_2$ . After the mixture had been stirred for eight hours, a nonionic flocculant (60.2 g of 0.1% HyChem NE-823) was added, and the mixture was allowed to flocculate for 20 minutes with slow agitation. The mixture was allowed to settle for two hours; then the supernatant was decanted into a five-gallon bucket. The total arsenic content of the primary supernatant was 290 ppb. After settling for an additional hour, the supernatant was transferred into a second five-gallon bucket. This solution also contained 290 ppb total arsenic. An aliquot of the second-stage supernatant was filtered through a 0.45-micron membrane. The filtrate contained 200 ppb arsenic.

Flocculated solids were vacuum-filtered on a Buchner funnel. The resulting filter cake (84.1% moisture) was submitted for TCLP analysis. The heavy metal composition of the TCLP leachate is summarized in Table 20.

**Table 20. TCLP Leachate Composition of Filter Cake from Test 2136-72  
(7:1 Iron-to-Arsenic Weight Ratio)**

Analyte	Concentration
Arsenic, ppm,	1.02
Barium, mg	0.44
Cadmium, mg	<0.025
Chromium, mg	<0.05
Lead, mg	<0.1
Mercury, mg	<0.002
Selenium, mg	<0.01
Silver, mg	<0.05

#### **Ferric Chloride and Air or Oxygen Oxidation**

A second test was conducted with ferric chloride at a 7:1 iron-to-arsenic weight ratio in Test 2136-73 to investigate the oxidizing efficiency of air for the conversion of arsenite to arsenate. In this test, a 400 g

aliquot of Groundwater Sample 47049-2 (168 ppm total arsenic) was aerated for 80 minutes by sparging with air at 150 ml per minute. The pH level of the water increased from 6.6 to 8.2 during the air sparging process. The solution was treated at a 7:1 iron-to-arsenic weight ratio with 2.28 g of  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  and mixed on a magnetic stir plate for 30 minutes. The pH level of the groundwater fell to 2.29 after the addition of iron treatment. The solution was neutralized to pH 6.0 with 0.86 g of solid  $\text{Ca}(\text{OH})_2$  and stirred for eight hours. Suspended solids were then flocculated with 0.4 g of 0.1% HyChem NE-823 and slowly agitated for 20 minutes. After two hours of settling time, the supernatant was decanted; then the material was settled for one hour and decanted again. The total arsenic content of the second-stage supernatant was 23.2 ppm. Filtered supernatant contained 20.2 ppm arsenic.

The test conditions for Test 2136-74 were identical to the previous test (2136-73), with the exception that the groundwater was sparged with oxygen rather than air for 80 minutes prior to addition of the ferric treatment. The results from this test are summarized in Table 21.

**Table 21. Results of Test 2136-74 Oxygen Sparged for 80 Minutes  
7:1 Iron-to-Arsenic Weight Ratio (Ferric Chloride)**

Groundwater Sample	47049-2
Sample Weight, g	400
Initial pH	6.67
pH after $\text{O}_2$ Sparging	8.32
$\text{FeCl}_3(6\text{H}_2\text{O})$	2.28
pH after Iron Treatment	2.29
Solid $\text{Ca}(\text{OH})_2$ to pH 6.0, g	0.79
Flocculant (0.1% active), g	0.38
Arsenic in Supernatant, ppm	18.5
Arsenic in Filtrate (0.45 micron), ppm	17.8

The results from this series of tests indicate that arsenic-contaminated groundwater can successfully be treated to an effluent arsenic concentration of less than 2 ppm with either ferric chloride or ferric sulfate

at a 7:1 iron-to-arsenic weight ratio. The treatment program should include a hydrogen peroxide preoxidation stage prior to addition of the ferric treatment. Both air and oxygen proved ineffective for the oxidation of arsenite.

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## SUMMARY AND CONCLUSIONS

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Bench-top beaker tests were conducted to evaluate iron coprecipitation as a treatment process for the removal of arsenic from contaminated groundwater. Both ferric- and ferrous-based treatment programs were evaluated. The results of these tests are summarized below.

- Contaminated groundwater can be treated to a 200 ppb discharge limit by either an oxidative ferrous or ferric coprecipitation process.
- Increased arsenic removal is obtained at higher Fe:As weight ratios.
- A nonoxidative ferric coprecipitation treatment program at a 15:1 Fe:As weight ratio, with  $\text{Ca}(\text{OH})_2$  neutralization and a 30-minute precipitation time, reduces the groundwater arsenic level from 150 ppm to around 130 ppb.
- An oxidative ferrous sulfate  $\text{H}_2\text{O}_2$  coprecipitation at a 15:1 Fe:As weight ratio, with  $\text{Ca}(\text{OH})_2$  neutralization and a 30-minute precipitation time, produces a treated solution with around 90 ppb arsenic.
- Increased arsenic removal is achieved at longer precipitation times.
- Longer precipitation times promote precipitation of  $\text{CaSO}_4$ .
- An oxidant must be added to the ferric treatment program to oxidize arsenite to arsenate prior to addition of  $\text{Fe}_2(\text{SO}_4)_3$ .
- A 2 ppm discharge limit can be achieved at a treatment level of 7:1 iron-to-arsenic weight ratio and preoxidation with hydrogen peroxide.
- Both air and oxygen proved ineffective for the oxidation of arsenite to arsenate.
- Preliminary block flow diagrams were developed for the treatment process to achieve an arsenic treatment goal of 200 and 50 ppb.

## PROCESS BLOCK FLOWSHEETS

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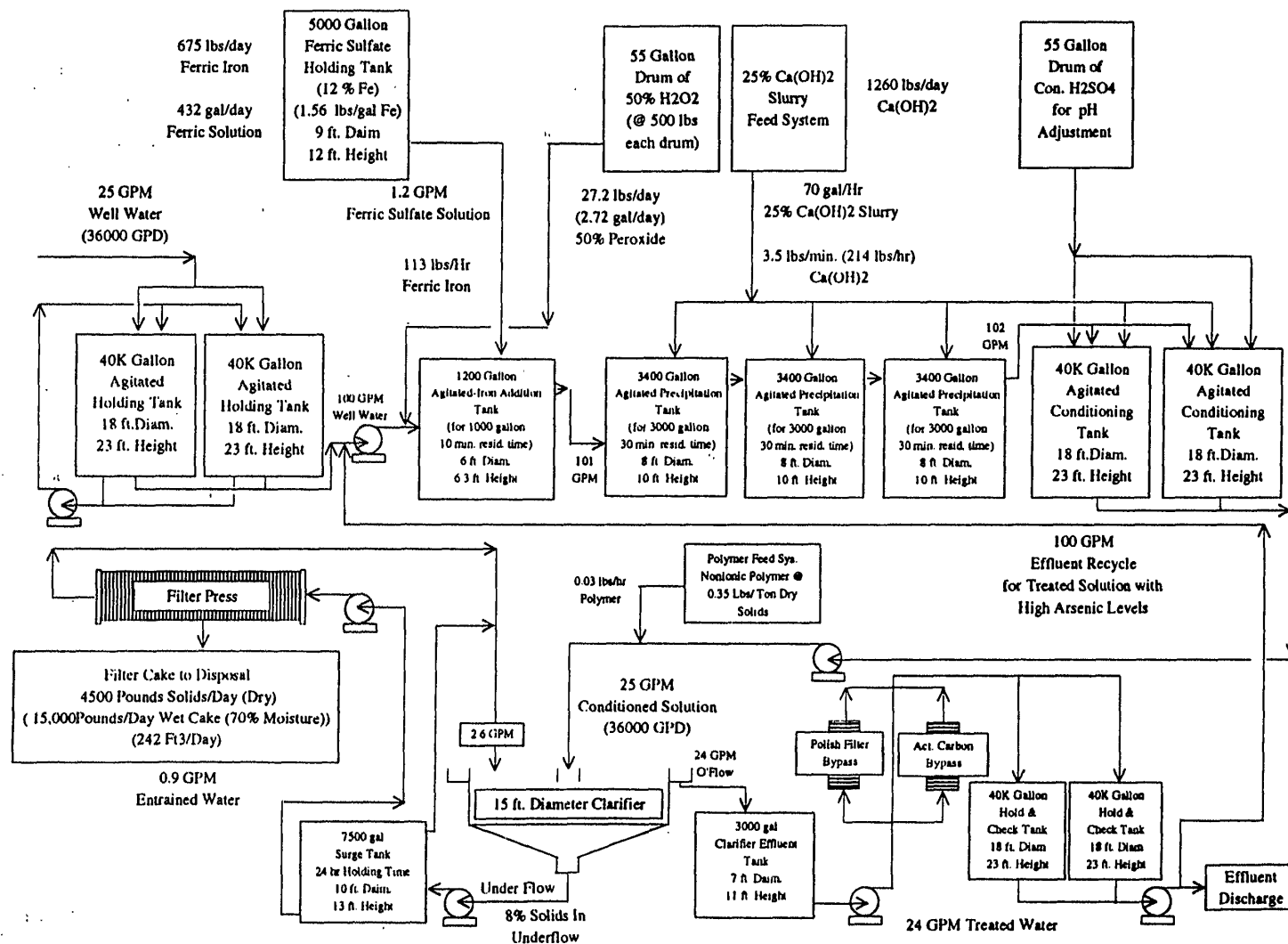
### FERRIC COPRECIPITATION FLOWSHEET FOR EFFLUENT WITH LESS THAN 200 PPB ARSENIC

Figure 4 illustrates a proposed ferric coprecipitation flowsheet for the treatment of contaminated groundwater with an effluent arsenic content of less than 200 ppb. The following assumptions were made during the development of the process.

- 1) Groundwater is pumped from the well field at a constant rate of 25 gallons per minute (gpm).
- 2) Untreated water is stored in holding tanks where the arsenic content is checked prior to treatment.
- 3) The iron addition/precipitation processes operate for six hours each day at a feed rate of 100 gpm.
- 4) Untreated groundwater is oxidized with  $H_2O_2$  prior to ferrous treatment.
- 5) Ferrous addition is conducted in a continuous-stirred tank reactor to provide a ten-minute residence time. Treated solution is gravity fed to the first precipitation tank through an overflow weir.
- 6) A three-tank cascading precipitation process is used to adjust the solution pH to 6.0. In the first tank, the pH of iron-treated liquor is adjusted to 5.0 with a  $Ca(OH)_2$  slurry. The effluent from this tank is gravity fed to the second tank, where the pH is adjusted to 5.5. In the final precipitation tank, the pH level of gravity-fed overflow from the second tank is adjusted to 6.0.
- 7) Effluent from the precipitation process is stored in one of two agitated holding tanks. These tanks provide a 24-hour conditioning period for  $CaSO_4$  precipitation and further coprecipitation of iron-arsenic species.



# Ferric Sulfate Treatment Process (<200 ppb Arsenic in Effluent)



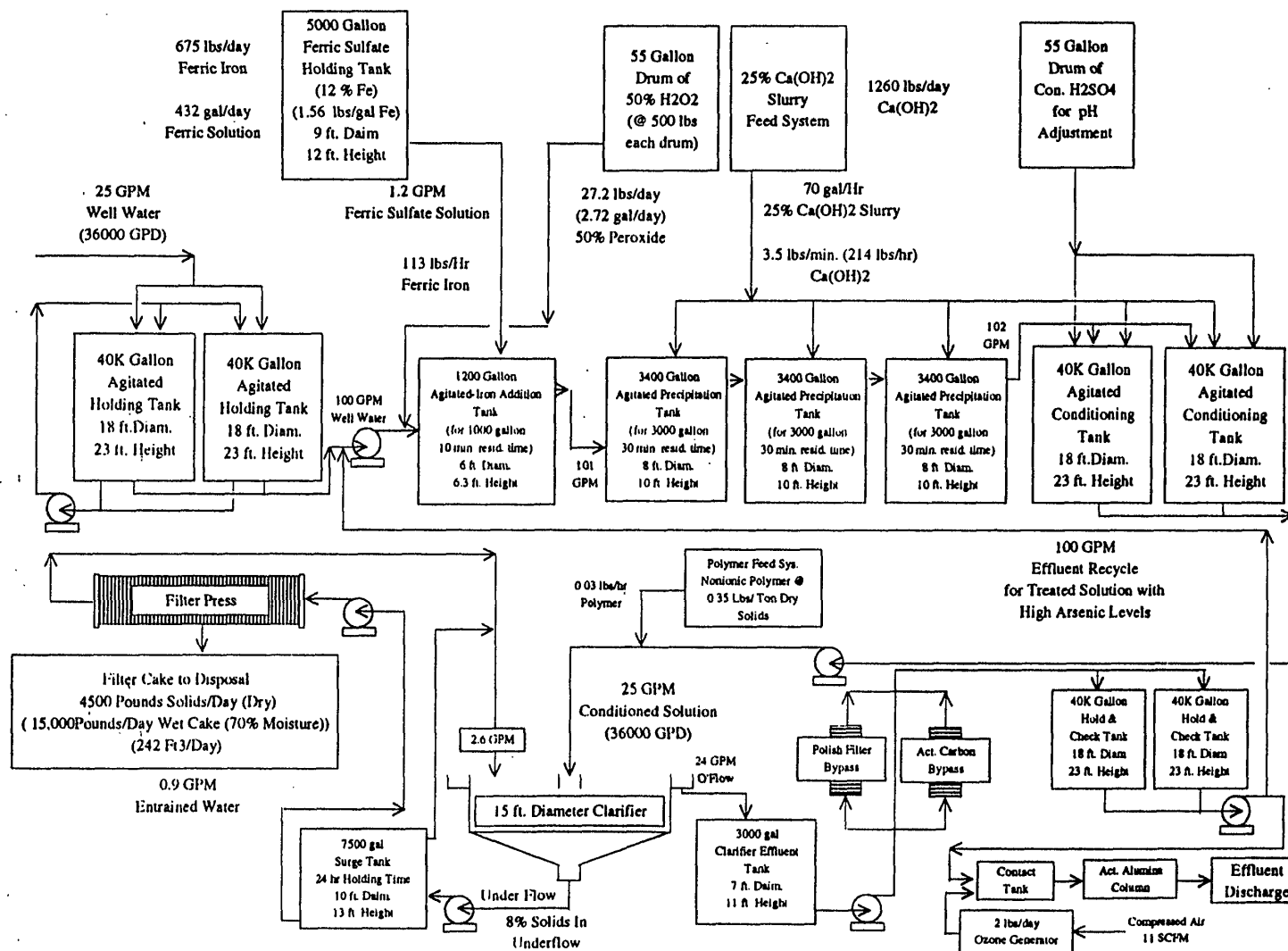
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- 8) Discharge from the conditioning tanks (25 gpm) continuously feeds a 15-foot-diameter clarifier. The solution is treated with a nonionic polymer prior to clarification. The clarifier feed contains 1.5% solids.
- 9) Underflow from the clarifier (8% solids) is stored in a surge tank (24-hour holding time).
- 10) A plate-and-frame filter press provides solid/liquid separation of surge tank slurry.
- 11) Clarifier overflow is treated with either a diatomaceous earth filter or activated carbon column.
- 12) Treated solution is stored in holding tanks where the arsenic level is determined. An effluent recycle system provides for treatment of effluent with high arsenic levels.

#### **FERRIC COPRECIPITATION FLOWSHEET FOR EFFLUENT WITH LESS THAN 50 PPB ARSENIC**

Figure 5 illustrates a theoretical ferric coprecipitation process for an effluent with a level of less than 50 ppb arsenic. A second-stage or tertiary oxidation/absorption operation has been added to the previously described process to achieve the treatment goal. Based on results of the operating Vineland Chemical New Jersey project it is not expected that consistent treat to 0.050 ppm can be achieved at full scale.

# Ferric Sulfate Treatment Process (<50 ppb Arsenic in Effluent)



**PHASE 3**  
**Optimization of a Ferric Coprecipitation Treatment**  
**Process to Achieve 2 ppm Discharge Limit**

**OVERVIEW**

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Phase III focused on optimizing a coprecipitation process. A series of tests was also conducted to investigate the corrosivity of neutralized ferric sulfate ( $\text{Fe}_2(\text{SO}_4)_3$ ) and ferric chloride ( $\text{FeCl}_3$ ) solutions on low-carbon steel (LCS) and 304 stainless steel (304 SS) corrosion coupons.

A series of batch precipitation tests were conducted to evaluate the efficacy of a ferric coprecipitation process for the removal of arsenic at various initial levels of arsenic contamination in an effort to simulate the probable initial influent mix and mass decline over time. Tests solutions were prepared by blending a composite groundwater sample containing 83 parts per million (ppm) arsenic with uncontaminated groundwater from Monitoring Well 12 (MW-12). Three levels of arsenic contamination were evaluated: 83, 42, and 21 ppm. The coprecipitation treatment program consisted of seven steps.

- 1) Add hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) to groundwater; oxidize arsenite to arsenate.
- 2) Add iron treatment ( $\text{Fe}_2(\text{SO}_4)_3$   $\text{FeCl}_3$ ) to groundwater.
- 3) Adjust pH of treated water to less than 2.5.
- 4) Stir for ten minutes.
- 5) Add 10% slurry of hydrated lime ( $\text{Ca}(\text{OH})_2$ ) to adjust pH to 6.0.
- 6) Agitate for 18 hours.
- 7) Flocculate with a nonionic polymer and clarify.

A Box-Wilson experimental design testing scheme was developed to investigate the effects of iron concentration,  $\text{H}_2\text{O}_2$  concentration, and degree of initial arsenic contamination on treatment efficacy. Initial tests were conducted with 400-gram (g) aliquots of contaminated composite groundwater or blended samples containing 25% composite groundwater and 75% MW-12 well water. A second series of 400 g beaker tests were conducted to evaluate intermediate arsenic and iron treatment levels.

The results of these tests demonstrated that arsenic-contaminated groundwaters were successfully treated at a 7:1 iron-to-arsenic ratio and two times stoichiometric  $\text{H}_2\text{O}_2$  to produce a filtered effluent with less

than 2 ppm arsenic. These conditions produced ferric hydroxide filter cakes that pass the Toxicity Characteristic Leaching Procedure (TCLP) protocol.

Large-scale batch tests indicated that  $\text{FeCl}_3$ -treated waters produce clear supernatants when flocculated with a nonionic polymer and conventional clarifier conditions. A solids-contact clarifier may be required to produce clear overflow from  $\text{Fe}_2(\text{SO}_4)_3$ -treated solutions.

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## TEST METHODS

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### TASK 1. CHARACTERIZATION OF GROUNDWATER SAMPLES

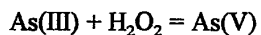
Hazen received three 55-gallon drums of groundwater from the Crystal Chemical facility for this study. The sample inventory consisted of two drums of uncontaminated groundwater from MW-12 and one drum which contained a composite solution from several arsenic-contaminated wells. To limit oxidation, the groundwater samples were shipped with no head space. Upon receipt at Hazen, samples of both the composite and uncontaminated groundwaters were removed for analysis, and a nitrogen purge placed on each drum to preserve the waters under an inert atmosphere.

A summary of the compositions of the two groundwaters is provided in Table 22. These results indicated a total arsenic concentration of 83 ppm in the composite groundwater sample. Results of the arsenic speciation analysis is summarized in Table 23.

### TASK 2. FERRIC IRON COPRECIPITATION TESTS

A series of 400-milliliter (ml) beaker tests was conducted to evaluate the efficacy of ferric coprecipitation treatments for the removal of arsenic to less than 2 ppm in the effluent. Four variables were investigated: weight ratio of iron to arsenic (10:1, 7:1, and 3:1), iron source ( $\text{Fe}_2(\text{SO}_4)_3$  or  $\text{FeCl}_3$ ),  $\text{H}_2\text{O}_2$  ratio (3:1, 2:1, and 1:1 stoichiometric chemical requirement for oxidation of arsenite and arsenate), and dilution of composite contaminated groundwater with MW-12 groundwater (neat composite, 50% composite and 50% MW-12, and 25% composite and 75% MW-12).

The oxidation of arsenite to arsenate by  $\text{H}_2\text{O}_2$  is described by the following equation:



The  $\text{H}_2\text{O}_2$  dosage was based on an arsenite concentration of 2.66 ppm (0.0355 mole per liter) in the neat composite groundwater sample.

Table 22. Characterization of Field Composite and Monitoring Well 12 Groundwaters

Analyte	Field Composite		MW-12	
	Filtered	Unfiltered	Filtered	Unfiltered
<b>Cations</b>				
Arsenic, ppm	83	83	<1	<1
Cadmium, ppm	0.003	0.002	<0.001	<0.001
Calcium, ppm	306	--	130	--
Chromium, ppm	<0.01	<0.01	<0.01	<0.01
Copper, ppm	0.04	0.03	0.02	0.02
Iron, ppm	0.17	0.29	0.03	0.03
Magnesium, ppm	120	--	44.3	--
Lead, ppm	0.001	0.021	<0.001	<0.001
Mercury, ppm	--	<0.1	--	<0.1
Nickel, ppm	0.12	0.09	0.03	0.03
Selenium, ppm	--	<0.005	--	<0.005
Silver, ppm	0.0023	0.0004	0.0003	0.0001
Sodium, ppm	510	--	170	--
<b>Anions</b>				
Alkalinity, ppm CaCO <sub>3</sub>	--	355	--	304
Chloride, ppm	--	777	--	302
Total Dissolved Solids, ppm	--	2,190	--	986
Total Suspended Solids, ppm	--	6	--	<5
Sulfate, ppm	--	238	--	114
Total Organic Carbon, ppm	--	15	--	1
pH		7.3		7.0
Conductivity, micromhos/cm		3,390		1,720
Redox Potential, mV		56		291
Dissolved Oxygen, ppm		5.9		2.8

Table 23. Results of Arsenic Speciation Analysis

Species	% as Arsenic	Arsenic in Composite Sample, ppm
Arsenite	3.2	2.7
Arsenate	5.4	4.5
Methyl Arsenic Acid	87.3	72.5
Cacodylic Acid	3.7	3.1

A Box-Wilson experimental design test program was developed to investigate the effects of each variable on arsenic removal. A copy of an article that explains the theory and application of this experimental design process is provided in Appendix C. The conditions of the first eight tests are outlined in the Box-Wilson worksheet provided in Figure 6.

#### Initial Beaker Tests

An initial series of nine experiments evaluated the relative effects of iron treatment level,  $H_2O_2$  concentration, and degree of contamination on arsenic removal. These tests were conducted with 400 g aliquots of neat contaminated composite groundwater or blended samples containing 25% composite groundwater and 75% MW-12 well water. At the start of each test, the pH levels of groundwater samples were recorded, and the waters were treated with either one or three times stoichiometric  $H_2O_2$  (from 0.5% solution). The groundwaters were then treated with either a  $Fe_2(SO_4)_3$  or  $FeCl_3$  solution at a 3:1 or 10:1 iron-to-arsenic weight ratio. The  $Fe_2(SO_4)_3$  and  $FeCl_3$  stock solutions contained by weight 10 and 8% iron, respectively. After iron addition, the pH levels were recorded and the treated groundwaters acidified to produce a clear solution (pH level less than 2.5). The  $FeCl_3$ -treated solutions were acidified with 1N HCl, while 10%  $H_2SO_4$  was used to adjust the pH of waters treated with  $Fe_2(SO_4)_3$ . The acidified waters were then mixed for ten minutes and neutralized to pH 6.0 with a 10%  $Ca(OH)_2$  solution. The resulting slurries were stirred for 30 minutes, flocculated with nonionic polyacrylamide polymer (HyChem NE 823), settled, and the supernatants filtered through 0.45-micron membrane filters. The filtrates were preserved with nitric acid, and the arsenic content was determined by graphite furnace spectroscopy. The results of the initial nine tests are summarized in Table 24.



Line			A	B	C	D	E	F	Interactions C = AB E = AD F = BD G = ABD					
1	Factors Studied		Fe:As	SO <sub>4</sub> /Cl	H <sub>2</sub> O <sub>2</sub>	% Dilution		Arsenic in Filtrate						
2	Base Line		6.5		2	37.5								
3	Unit		3.5		1	37.5								
4	High Level		10	SO <sub>4</sub>	3	0			H	J	K	L	M	N
5	Low Level		3	Cl	1	75			% Arsenic Removal	Calculation			Effects of Factors	
6	Sample 1	Test 5	3	Cl	3	0								Average
7	2	7	10	Cl	1	0								B
8	3	8	3	SO <sub>4</sub>	1	0								C
9	4	2	10	SO <sub>4</sub>	3	0								
10	5	4	3	Cl	3	75								D
11	6	6	10	Cl	1	75								
12	7	1	3	SO <sub>4</sub>	1	75								
13	8	3	10	SO <sub>4</sub>	3	75								A
14														

Figure 6. Test Scheme for Precipitation Tests

Table 24. Results of Initial Beaker Tests

Test No.	Fe:As Weight Ratio	Iron Source	H <sub>2</sub> O <sub>2</sub> :As(3+) Stoich. Ratio	% Composite in Test Solution	Initial Arsenic ppm	Final Arsenic ppm
1	3:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	1	25	21	2.36
2	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3	100	83	2.26
3	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3	25	21	0.182
4	3:1	FeCl <sub>3</sub>	3	25	21	1.63
5	3:1	FeCl <sub>3</sub>	3	100	83	4.86
6	10:1	FeCl <sub>3</sub>	1	25	21	1.34
7	10:1	FeCl <sub>3</sub>	1	100	83	3.52
8	3:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	1	100	83	6.58
15 Rerun No. 2	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3	100	83	0.22

A summary of test conditions and reagent consumption is provided in Table 25.

In Test No. 2, neat (as-received) groundwater was treated at a 10:1 iron-to-arsenic weight ratio and three times the stoichiometric level of peroxide. The pH of the treated groundwater dropped to approximately 2.8 after addition of the iron treatment. In this test, no acid was added to the test solution to reduce the solution pH below 2.5. During the ten-minute mixing period, the pH level of the test solution dropped to around 2.6, and ferric hydroxide flocs began to form, turning the solution turbid. The solution was neutralized with 10% Ca(OH)<sub>2</sub>, stirred for 30 minutes, flocculated, and the supernatant filtered through a 0.45-micron filter. This test produced a filtrate containing 2.26 ppm total arsenic.

The test conditions and treatment levels of Test No. 2 were duplicated in Test No. 15. In the latter test, however, the solution was acidified to pH 2.4 after addition of the iron treatment. During this test, solution remained clear until neutralized with Ca(OH)<sub>2</sub>. The filtered supernatant from this test contained 0.22 ppm total arsenic.

The results of these two tests indicate that coprecipitation efficacy is enhanced if the groundwater is acidified to a pH level of less than 2.5 after addition of the iron treatment. The pH adjustment is necessary to allow uniform dispersion of iron before formation of ferric hydroxide precipitates. At pH levels above 2.5, iron is precipitated before complete iron dispersion is achieved.

Table 25. Results of Precipitation Tests

Run No.	Sample Size, l	Dilution Cont. Water	H <sub>2</sub> O <sub>2</sub> Solch. Ratio	Fe:As Ratio Weight	Fe Source	pH After Iron Added	Grams Acid*	pH After Acid	10% Ca(OH) <sub>2</sub> to pH 6, g	Arsenic in Filtrate, ppm
1	0.40	75	1	3:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	6.84	5.78	2.2	1.92	2.36
2	0.40	0	3	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.65	--	2.65	4.84	2.26
3	0.40	75	3	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3.76	4.02	2.3	1.68	0.182
4	0.40	75	3	3:1	FeCl <sub>3</sub>	6.8	4.9	2.3	1.82	1.63
5	0.40	0	3	3:1	FeCl <sub>3</sub>	3.1	2.34	2.49	1.06	4.86
6	0.40	75	1	10:1	FeCl <sub>3</sub>	3.28	3.14	2.4	1.01	1.34
7	0.40	0	1	10:1	FeCl <sub>3</sub>	2.7	2.47	2.4	3.53	3.52
8	0.40	0	1	3:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3.75	4.64	2.4	1.59	6.58
9	0.40	9.3	2.2	9:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.88	11.27	1.7	9.32	0.37
10	0.40	0	2.4	11.5:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.77	1.89	2.4	5.42	0.25
11	0.40	9.3	2.2	9:1	FeCl <sub>3</sub>	2.56	0.69	2.4	4.52	0.96
12	0.40	0	2.4	11.5:1	FeCl <sub>3</sub>	2.40	--	2.4	6.42	0.79
13	0.40	50	2	10:1	FeCl <sub>3</sub>	2.66	1.98	2.3	3.22	0.57
14	0.40	50	2	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.89	3.53	2.1	3.21	0.20
15	0.40	0	3	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.85	1.80	2.4	3.95	0.22
16	0.40	0	2	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.80	2.10	2.1	3.36	0.46
17	0.40	50	2	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3.21	2.98	2.17	2.28	0.49
18	0.40	75	2	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	5.63	2.20	2.4	2.67	0.54
19	0.40	0	2	7:1	FeCl <sub>3</sub>	2.60	1.91	2.3	5.07	0.15
20	0.40	50	2	7:1	FeCl <sub>3</sub>	2.68	1.24	2.4	2.57	0.46
21	0.40	75	2	7:1	FeCl <sub>3</sub>	3.38	2.70	2.4	1.82	0.49
22	22	75	2	7:1	FeCl <sub>3</sub>	3.8	160.2	2.2	80.5	0.68
23	22	75	2	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	5.7	108.0	2.2	86.2	0.90
24	22	50	2	7:1	FeCl <sub>3</sub>	2.6	7.5	2.4	106.6	0.45
25	22	50	2	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3.0	87.7	2.2	148.6	0.73
26	22	0	2	7:1	FeCl <sub>3</sub>	2.4	--	2.4	209.7	0.51
27	22	0	2	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.5	77.9	2.0	92.99	0.47

\* 1N HCl added to solution treated with ferric chloride, 10% H<sub>2</sub>SO<sub>4</sub> added to solutions treated with ferric sulfate. •

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The results of these tests were entered into the experimental design worksheet, Figure 7, and the relative response of each variable was estimated. Preliminary conclusions indicate that the average arsenic removal for the eight tests was 94.4%, which is also the expected amount of arsenic removed at baseline conditions (6.5:1 iron-to-arsenic weight ratios, 2:1 mole ratio of  $\text{H}_2\text{O}_2$ :arsenite, and solution mixture of 62.5% composite, 37.5 MW-12). The estimated arsenic level in filtered supernatant under baseline conditions is 2.9 ppm. Increased iron and  $\text{H}_2\text{O}_2$  treatment levels appear to provide greater removal of arsenic from contaminated groundwaters. Treatment efficacy, however, is reduced at lower initial arsenic levels. The results from these tests also indicate that, at a given level of iron treatment, groundwaters treated with  $\text{Fe}_2(\text{SO}_4)_3$  will produce lower filtered effluent arsenic levels than waters treated with  $\text{FeCl}_3$ .

In previous coprecipitation studies conducted for the subject account (HRI Project 8068), it was noted that the addition of ferric iron to groundwaters containing high levels of arsenic (150 to 160 ppm total arsenic) produced clear solutions with pH levels of less than 2.5. Since both  $\text{Fe}_2(\text{SO}_4)_3$  and  $\text{FeCl}_3$  form acidic solutions when dissolved in water, this acidity is available to consume alkalinity and reduce the pH levels of the treated solutions. This effect was observed at iron-to-arsenic weight ratios ranging from 7:1 to 15:1.

In the present series of tests, however, the ferric treatment produced turbid solutions with pH levels ranging from 2.65 (neat composite found water, 10:1 iron-to-arsenic weight ratio) to 6.84 (25% composite, 75% MW-12, 3:1 iron-to-arsenic weight ratio). Since less iron was used to treat waters in the current study, insufficient acidity was available to reduce the pH level below 2.5. Under these conditions, the coprecipitation treatment program should include an acidification step to reduce the pH level of iron treated waters below 2.5 before neutralization with  $\text{Ca}(\text{OH})_2$ .

#### Confirmatory Beaker Tests

An additional set of six beaker tests was conducted to confirm trends identified in the original series of tests. The results of these tests are summarized in Table 26.

The results in Table 26 illustrate that arsenic-contaminated groundwaters should be treated with at least two times the stoichiometric amount of  $\text{H}_2\text{O}_2$  needed to oxidize arsenite to arsenate. The  $\text{Fe}_2(\text{SO}_4)_3$ -treated solutions consistently produced lower filtered effluent arsenic levels than solutions treated with  $\text{FeCl}_3$  under similar conditions.

Line														
1	Factors		A	B	C	D	E	F	Interactions C = AB E = AD F = BD G = ABD					
2	Studied		Pb:As	SO4/Cl	H2O2	% Dilution		Arsenic in Filtrate						
3	Base Line		6.5		2	37.5								
4	Unit		3.5		1	37.5								
5	High Level		10	SO4	3	0			H	J	K	L	M	N
6	Low Level		3	Cl	1	75			% Arsenic Removal	Calculation			Effects of Factors	
7	Sample 1	Test 5	3	Cl	3	0		4.86	94.14	189.9	381.7	755.2	94.4	Average
8	2	7	10	Cl	1	0		3.52	95.76	191.8	373.5	21.14	2.6	B
9	3	8	3	SO4	1	0		6.58	92.07	185.7	9.277	3.961	0.5	C
10	4	15	10	SO4	3	0		0.22	99.73	187.8	11.87	15.13		
11	5	4	3	Cl	3	75		1.63	92.16	1.61	1.90	-8.21	-1.0	D
12	6	6	10	Cl	1	75		1.34	93.56	7.66	2.06	2.59		
13	7	1	3	SO4	1	75		2.36	88.65	1.39	6.05	0.15		
14	8	3	10	SO4	3	75		0.182	99.13	10.47	9.08	3.03	0.4	A

Figure 7. Test Scheme and Results for Precipitate Tests

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Table 26. Results of Initial Beaker Tests

Test No.	Fe:As Weight Ratio	Iron Source	H <sub>2</sub> O <sub>2</sub> :As(3+) Stoich. Ratio	% Composite in Test Solution	Initial Arsenic ppm	Final Arsenic ppm
9	9:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.2	90.7	75	0.37
10	11.5:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.4	100	83	0.25
11	9:1	FeCl <sub>3</sub>	2.2	90.7	75	0.96
12	11.5:1	FeCl <sub>3</sub>	2.4	100	83	0.79
13	10:1	FeCl <sub>3</sub>	2.0	50	42	0.57
14	10:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.0	50	42	0.20

#### Coprecipitation Beaker Tests at Intermediate Iron Treatment Levels

A final series of six beaker tests was conducted to evaluate the efficacy of the ferric coprecipitation process at an intermediate iron-to-arsenic weight ratio of 7:1. These tests were conducted at two times stoichiometric amount of H<sub>2</sub>O<sub>2</sub> (based on oxidation of arsenite to arsenate) and three groundwater compositions: neat composite, 50% composite and 50% MW-12, and 25% composite and 75% MW-12. The results of these tests are summarized in Table 27.

Table 27. Results of Beaker Tests at 7:1 Iron:Arsenic Weight Ratio and Two Times Stoichiometric Level of H<sub>2</sub>O<sub>2</sub>

Test No.	Fe:As Weight Ratio	Iron Source	H <sub>2</sub> O <sub>2</sub> :As(3+) Stoich. Ratio	% Composite in Test Solution	Initial Arsenic ppm	Final Arsenic ppm
16	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.0	100	83	0.46
17	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.0	50	42	0.49
18	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.0	25	21	0.54
19	7:1	FeCl <sub>3</sub>	2.0	100	83	0.15
20	7:1	FeCl <sub>3</sub>	2.0	50	42	0.46
21	7:1	FeCl <sub>3</sub>	2.0	25	21	0.49

A summary of reagent consumption and test conditions is provided in Table 25. As with previous tests, the solutions were acidified with either 1N HCl or 10% H<sub>2</sub>SO<sub>4</sub> after addition of the iron treatment to reduce the pH of the solutions to less than 2.5. The results from these tests illustrate that contaminated groundwaters are successfully treated to a filtered effluent arsenic level of less than 2 ppm at treatment levels of 7:1 iron-to-arsenic ratio and two times stoichiometric H<sub>2</sub>O<sub>2</sub>.

Vacuum filter cakes from Tests 16 and 19 were subjected to a modified TCLP in which a 1.85 g filter cake from Test 16 was leached in 37 g of extraction solution No. 1 and 3.46 g of Test 19 filter cake was leached in 69.2 g of extraction solution. The filter cakes passed the TCLP protocol, with leachate arsenic concentrations of 1.21 ppm for solids from Test 16 and 1.24 ppm for Test 19. The regulatory limit for the extract arsenic concentration is 5.0 ppm.

### Large-scale Coprecipitation and Settling Tests

Six 22-kilogram (kg) batch precipitation tests were performed at a 7:1 iron-to-arsenic weight ratio and two times stoichiometric H<sub>2</sub>O<sub>2</sub>. These tests were conducted to confirm results from Tests 16 through 21, develop settling curves for flocculated solids, and produce sufficient filter cake for TCLP analysis at each treatment condition. The results of these tests are summarized in Table 28.

During these tests, seven-gallon plastic buckets were charged with 22 kg of groundwater and agitated with an overhead mixer. The arsenic concentrations of the test solutions were adjusted by adding uncontaminated groundwater from MW-12 to a contaminated composite groundwater sample containing 83 ppm total arsenic. The groundwater mixtures evaluated were 16.5 kg of MW-12 with 5.5 kg of composite (20.8 ppm total arsenic), 11 kg of MW-12 with 11 kg of composite (41.5 ppm total arsenic), and neat composite (83 ppm total arsenic). The solutions were treated with two times stoichiometric H<sub>2</sub>O<sub>2</sub> and ferric iron at a 7:1 iron-to-arsenic weight ratio. After addition of the iron treatment, the pH levels of the groundwaters were adjusted to less than 2.5. Groundwaters treated with Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> were acidified with 10% H<sub>2</sub>SO<sub>4</sub>, while the pH levels of FeCl<sub>3</sub>-treated waters were adjusted with 1N HCl. After stirring for ten minutes, the solutions were neutralized to pH 6 with 10% slurry of Ca(OH)<sub>2</sub> and mixed for 18 hours. The solutions were then flocculated with a nonionic polyacrylamide of moderate to high molecular weight. The settling characteristics of flocculated solids were investigated under a simulated conventional clarifier and solids-contact clarifier conditions.

The results from these tests confirm previous small-scale beaker studies, with all of the treated solutions producing clarifier supernatants with arsenic levels of less than 2 ppm. The solids

Table 28. Results of Large-scale Precipitation Tests

Test No.	Sample Size, l	% Dilution of Contaminated Groundwater	H <sub>2</sub> O <sub>2</sub> :As(3) Mole Ratio	Fe:As Weight Ratio	Fe Source	pH After Iron Added	Grams Acid*	pH After Acid	10% Ca(OH) <sub>2</sub> to pH 6, g	% Solids in Filter Cake	Arsenic in Filter Cake TCLP Leachate ppm	Arsenic in Supernatant ppm <sup>1</sup>	Arsenic in Supernatant ppm <sup>2</sup>
22	22	75	2:1	7:1	FeCl <sub>3</sub>	3.8	160.2	2.2	80.5	5.4	1.15	0.68	--
23	22	75	2:1	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	5.7	108.0	2.2	86.2	7.2	1.28	0.9	--
24	22	50	2:1	7:1	FeCl <sub>3</sub>	2.6	7.5	2.4	106.6	5.5	1.66	0.45	--
25	22	50	2:1	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	3.0	87.7	2.2	148.6	14	1.62	0.87	0.73
26	22	0	2:1	7:1	FeCl <sub>3</sub>	2.4	--	2.4	209.7	4.4	1.43	0.51	--
27	22	0	2:1	7:1	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	2.5	77.9	2.0	193	18	1.69	1.16	0.47

\* 1N HCl added to solution treated with ferric chloride, 10% H<sub>2</sub>SO<sub>4</sub> added to solutions treated with ferric sulfate.

<sup>1</sup> Conventional clarifier.

<sup>2</sup> Solids-contact clarifier

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precipitated with  $\text{FeCl}_3$  developed a clearer supernatant under conventional clarifier conditions. Solids-contact clarifier conditions were required to produce a clear supernatant in solutions treated with  $\text{Fe}_2(\text{SO}_4)_3$ .

Pocock Industries, Inc. conducted the studies of settling and solids densities for this project. The results of these tests are provided in Appendix D.

Filter cakes from the settling tests were submitted for a modified TCLP analysis in which 10 g of moist filter cakes were leached with 200 g of Extractant No. 1. All of the filter cakes produced TCLP leachates with arsenic levels below the regulatory limit of 5 ppm. The results of the TCLP analysis are summarized in Table 29.

### TASK 3. CORROSION TESTS

The corrosion characteristics of ferric coprecipitated slurries on LCS and 304 SS metallurgy were investigated in bench-scale beaker tests. In these tests, 800 g aliquots of contaminated groundwater from Monitoring Well 20 (400 ppm total arsenic) were treated with either  $\text{Fe}_2(\text{SO}_4)_3$  or  $\text{FeCl}_3$  at 15:1 weight ratios of iron to arsenic and neutralized to pH 6 with 10%  $\text{Ca}(\text{OH})_2$ . The two solutions were agitated on a magnetic stir plate, and pH levels of the slurries were maintained at 6 throughout the seven-day test.

The corrosion characteristics of each solution were determined by suspending preweighed LCS and 304 SS corrosion coupons in the stirred coprecipitate slurries for seven days. Two coupons of each metallurgy were suspended in each slurry. At the end of the test period, the coupons were removed, cleaned with a mixture of pumice and trisodium phosphate, and weighed. The weight losses of the corrosion coupons were used to estimate the relative corrosivity of each coprecipitated slurry. Table 30 summarizes the coupon weight losses.

The LCS corrosion coupons from the  $\text{Fe}_2(\text{SO}_4)_3$ -treated solution were covered with a thick layer of orange deposit with small tubercles along one edge of each coupon. Severe, localized pitting was noted beneath the tubercles. The LCS corrosion coupons from this test demonstrated an average weight loss of 24.2 milligrams per day (mg/d). Photographs of the coupons are provided in Figures 8 and 9.

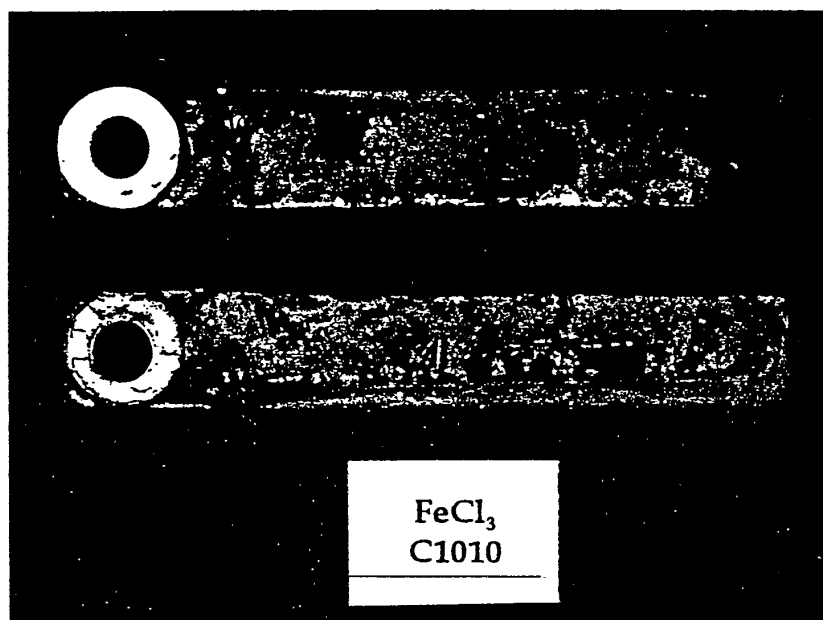


Figure 8. LCS Corrosion Coupons from  $\text{Fe}_2(\text{SO}_4)_3$  Solution

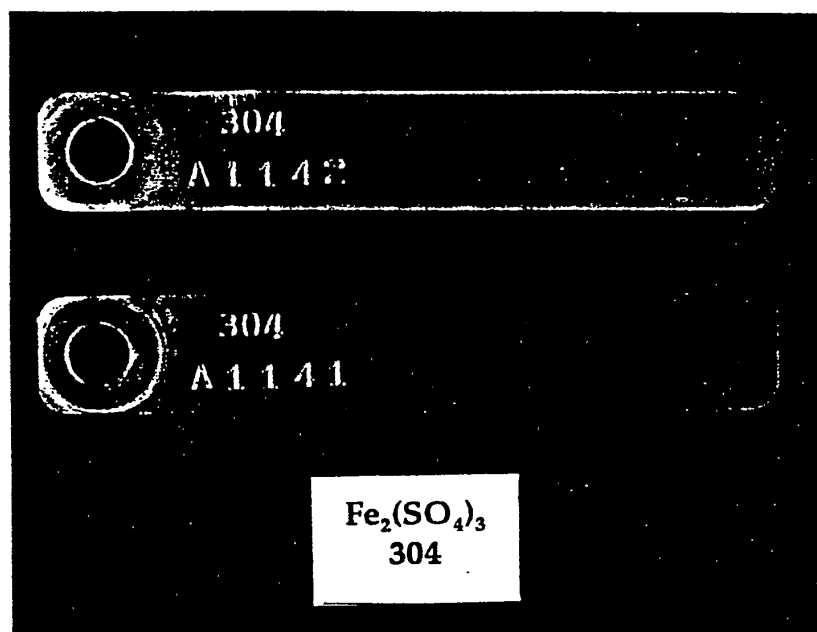


Figure 9. Cleaned LCS Corrosion Coupons from  $\text{Fe}_2(\text{SO}_4)_3$  Solution

**Table 29. Results of TCLP Analysis of Coprecipitate Filter Cakes**

	Test 16	Test 19	Test 22	Test 23	Test 24	Test 25	Test 26	Test 27
Fe:As	7:1	7:1	7:1	7:1	7:1	7:1	7:1	7:1
Dilution of Composite Sample, %	0	0	75	75	50	50	0	0
Hydrogen Peroxide	2	2	2	2	2	2	2	2
Sample Size, kg	0.4	0.4	22	22	22	22	22	22
Iron Source	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	FeCl <sub>3</sub>	FeCl <sub>3</sub>	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	FeCl <sub>3</sub>	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	FeCl <sub>3</sub>	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>
TCLP Leachate Analyte, ppm								
Arsenic	1.21	1.24	1.15	1.28	1.66	1.62	1.43	1.69
Barium	0.08	<0.05	0.11	0.20	0.06	0.12	<0.05	<0.05
Cadmium	0.048	<0.025	<0.025	<0.025	0.138	0.138	<0.025	<0.025
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Mercury	0.007	<0.002	<0.002	<0.002	0.007	0.006	<0.002	0.008
Selenium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Arsenic in Supernatant, ppm								
Filtered Supernatant	0.46	0.15	--	--	--	--	--	--
Conventional Clarifier Simulation	--	--	0.68	0.90	0.45	0.87	0.51	1.16
Solids-contact Clarifier Simulation	--	--	--	--	--	0.73	--	0.47

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Table 30. Corrosion Coupon Weight Loss

Iron Source	Coupon Metallurgy	Metallurgy I.D. Number	Initial Weight, g	Final Weight, g	Weight Loss, g
$\text{Fe}_2(\text{SO}_4)_3$	LCS	AA5706	10.7630	10.6029	0.1601
$\text{Fe}_2(\text{SO}_4)_3$	LCS	AA5707	10.8096	10.6298	0.1798
$\text{Fe}_2(\text{SO}_4)_3$	304 SS	AA1142	10.6929	10.6922	0.0007
$\text{Fe}_2(\text{SO}_4)_3$	304 SS	AA1141	10.6690	10.6684	0.0006
$\text{FeCl}_3$	LCS	AA5701	10.9050	10.6888	0.2162
$\text{FeCl}_3$	LCS	AA5702	10.8281	10.6090	0.2191
$\text{FeCl}_3$	304 SS	AA1144	10.5682	10.5676	0.0006
$\text{FeCl}_3$	304 SS	AA1143	10.6024	10.6020	0.0004

The LCS corrosion coupons from the  $\text{FeCl}_3$ -treated solution developed a higher average weight loss rate of 31.1 mg/d. These coupons were coated with thick orange deposition and a film of tenacious black tarnish. No pitting was noted. Photographs of the coupons are provided in Figures 10 and 11.

These results indicate that although the LCS metallurgy from the  $\text{Fe}_2(\text{SO}_4)_3$  developed a limited amount of edge corrosion, the overall LCS corrosion rate of the  $\text{Fe}_2(\text{SO}_4)_3$  slurry was lower than the corrosion rate developed in the  $\text{FeCl}_3$ -treated solution.

The 304 SS corrosion coupons from each test were coated with a thin oxide film which was easily removed during the cleaning operation. The  $\text{Fe}_2(\text{SO}_4)_3$ -treated solution developed an average 304 SS weight loss of 0.093 mg/d, the  $\text{FeCl}_3$  solution, an average corrosion rate of 0.071 mg/d. These results indicate that both solutions exhibited low corrosion potential for 304 SS metallurgy. Photographs of the 304 SS coupons are provided in Figures 12 and 13.

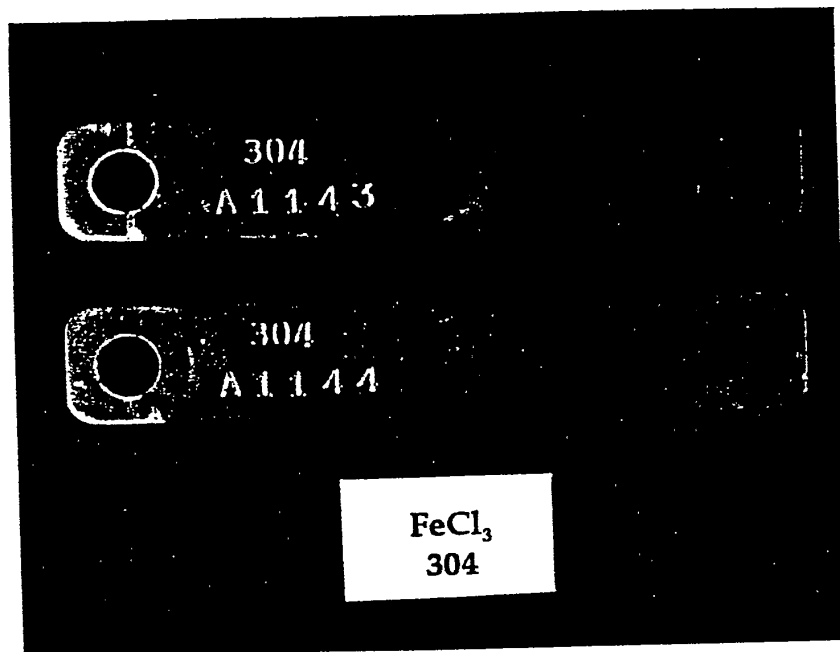


Figure 10. LCS Corrosion Coupons from FeCl<sub>3</sub> Solution

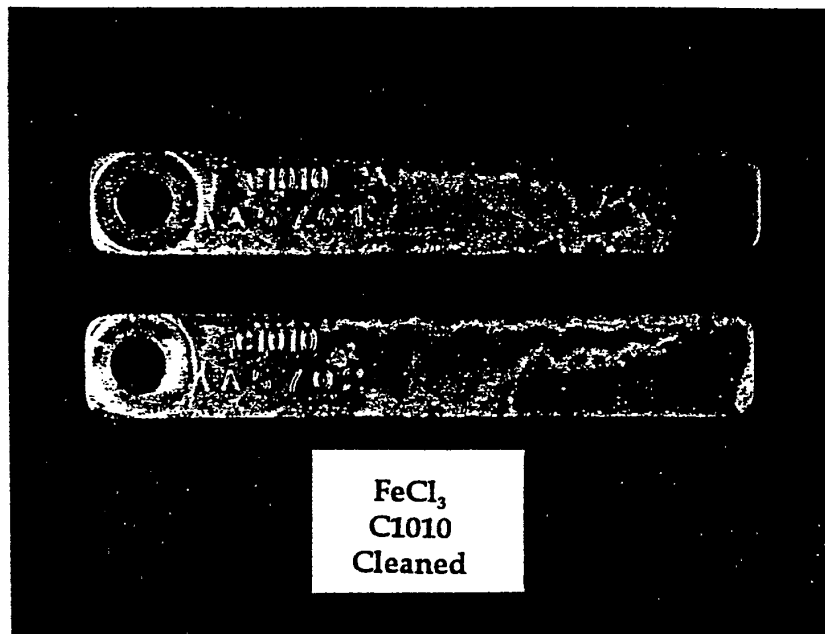


Figure 11. Cleaned LCS Corrosion Coupons from  $\text{FeCl}_3$  Solution

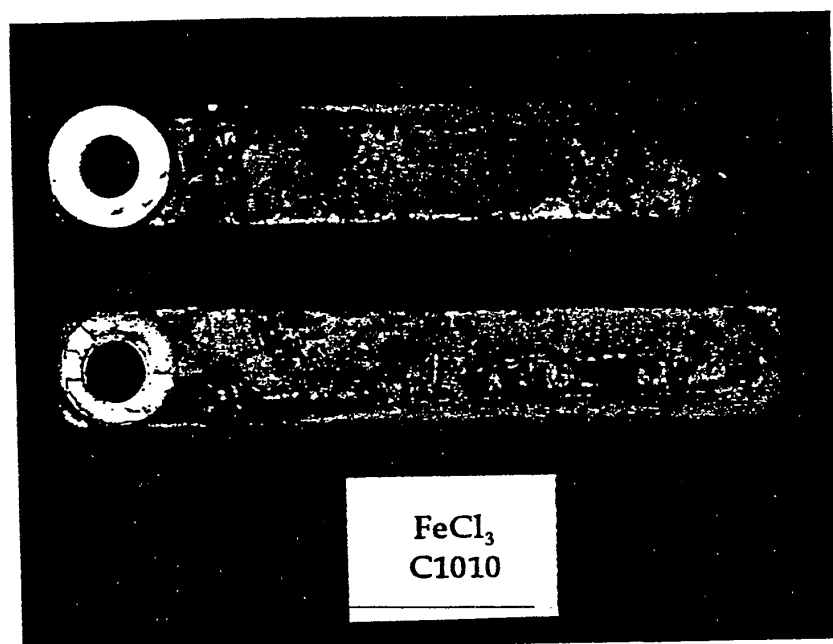


Figure 12. 304 Stainless Steel Corrosion Coupons from  $\text{Fe}_2(\text{SO}_4)_3$  Solution



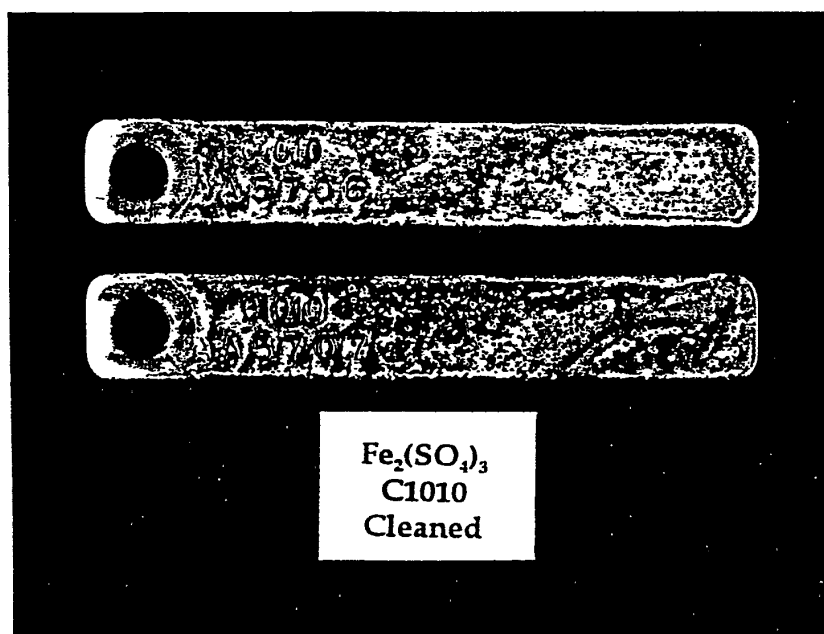


Figure 13. 304 Stainless Steel Corrosion Coupons from  $\text{FeCl}_3$  Solution

## CONCLUSIONS

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The results of this study indicate that groundwater contaminated with as little as 21 ppm total arsenic can be treated with a ferric coprecipitation process at minimum treatment levels of 7:1 iron-to-arsenic weight ratio and a 2:1 mole ratio of  $H_2O_2$  to arsenite. In groundwaters containing less than 150 ppm total arsenic, an acidification step should be included after addition of the iron treatment. The acidification step is needed to assure that the pH of the treated solutions is below 2.5 for complete dispersion of dissolved iron. The acidification step can be omitted when treating groundwaters with higher levels of arsenic contamination, as the increased acidity from higher iron treatment concentrations is sufficient to consume alkalinity and reduce the pH of the treated solution below 2.5. This process scheme appears to be the most appropriate for meeting the 2.0 ppm arsenic discharge limit to the city of Houston POTW. Other salient conclusions from the study as they relate to full scale design include the following:

- ◆ The arsenite levels in groundwater feed should be monitored to assure proper  $H_2O_2$  feed rates. The peroxide feed should be set to achieve a minimum 2:1 mole ratio of  $H_2O_2$ :arsenite.
- ◆ Neutralized solutions should be flocculated with a nonionic polyacrylamide electrolyte of moderate to high molecular weight.
- ◆ Solutions treated with  $FeCl_3$  will produce a clear supernatant in a conventional clarifier. A solids-contact clarifier may be needed to process  $Fe_2(SO_4)_3$ -treated solutions.
- ◆ Neutralized  $FeCl_3$ -treated solutions were more corrosive to LCS corrosion coupons than were  $Fe_2(SO_4)_3$ -treated solutions. No significant differences were noted on 304 SS metallurgy.

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## APPENDIX A

GRAVITY SEDIMENTATION  
PRESSURE FILTRATION  
VACUUM FILTRATION  
AND  
PULP RHEOLOGY STUDIES

CONDUCTED  
FOR

HAZEN RESEARCH INC.

PROJECT #8068

ARSENIC REMOVAL PROJECT

JULY 1993

(AMENDED AUGUST 1993)

PREPARED BY:

POCOCK INDUSTRIAL, INC.  
3605 SOUTH WEST TEMPLE  
SALT LAKE CITY, UT 84115  
801/265-9000; FAX 801/265-9852

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## EXECUTIVE SUMMARY

Results of the testing program reported herein support the following conclusions:

1. A medium to high molecular weight nonionic polyacrylamide flocculant can be used to enhance the settling characteristics of either the ferric or ferrous arsenate precipitates.
2. Design of a conventional thickener for duty on *ferric arsenate precipitate* should be based on the following criteria:
  - a. Unit Area requirement of 38.0 ft<sup>2</sup>/STPD for the production of 8% solids underflow.
  - b. Feed solids concentration of 1.5% - 2.2%, at pH 5.9.
  - c. Nonionic flocculant dosage in the range of 0.32-0.44 lbs/ST.
3. Design of a conventional thickener for duty on *ferrous arsenate precipitate* should be based on the following criteria:
  - a. Unit Area requirement of 59.0 ft<sup>2</sup>/STPD for the production of 8% solids underflow.
  - b. Feed solids concentration of 1.2% - 2.0%, at pH 5.9.
  - c. Nonionic flocculant dosage in the range of 0.40-0.48 lbs/ST.
4. Sizing of recessed plate filter presses to dewater *ferric arsenate precipitate* should be based on the following design criteria:

### Thickened (Ferric) Precipitate

Filter Feed Solids:	4.8 - 8.0%
Cake Thickness:	2.0 inches
Cake Moisture:	69%
Wet Bulk Density:	75.1 lbs/ft <sup>3</sup>
Sizing Basis:	107.4 ft <sup>3</sup> /ST (dry solids)



5. Sizing of recessed plate filter presses to dewater *ferrous arsenate precipitate* should be based on the following design criteria:

Thickened (Ferrous) Precipitate

Filter Feed Solids:	3.8 - 8.0%
Cake Thickness:	2.0 inches
Cake Moisture:	71%
Wet Bulk Density:	80.3 lbs/ft <sup>3</sup>

Sizing Basis: 107.4 ft<sup>3</sup>/ST (dry solids)

6. Sizing of rotary drum vacuum filters (scraper-type) to dewater *ferric arsenate precipitate* can be based on the following design criteria:

Thickened (Ferric) Precipitate

Filter Feed Solids:	4.8 - 8.0%
Cake Thickness:	3/8 inch
Cake Moisture:	71.0%
Wet Bulk Density:	75.0 lbs/ft <sup>3</sup>

Production Rate: 0.76 dry lbs/ft<sup>2</sup>•hr

7. Sizing of rotary drum vacuum filters (scraper-type) to dewater *ferrous arsenate precipitate* can be based on the following design criteria:

Thickened (Ferrous) Precipitate

Filter Feed Solids:	3.8 - 8.0%
Cake Thickness:	3/8 inch
Cake Moisture:	74.0%
Wet Bulk Density:	76.3 lbs/ft <sup>3</sup>

Production Rate: 0.43 dry lbs/ft<sup>2</sup>•hr

8. The oxidation state of iron, ferric or ferrous, is the primary factor influencing the apparent viscosity of the arsenate precipitate thickener underflow pulp, with the Iron (II) specie being the most viscous. However, unless over-flocculation is practiced, no pumping, mixing or pulp transport problems are anticipated.

## **INTRODUCTION**

Gravity sedimentation, pressure filtration, vacuum filtration and pulp rheology tests were conducted on samples of ferric and ferrous arsenate precipitates produced under Hazen Research Inc. Project #8068. The samples were produced during treatability and flow sheet development studies conducted by Hazen Research Inc. The range of samples tested is discussed in the Scope of Testing section which follows.

Present investigations were conducted at the Hazen Research Inc. laboratory facilities during July 1993. The responsibility for the selection of samples to be tested was borne Hazen Research Inc. personnel. Accordingly, samples presented to Pocock Industrial for testing were assumed to represent material likely to be encountered in an operating plant and thus, form the basis for the analyses and recommendations reported herein.

## **SCOPE OF TESTING**

The scope of the testing program included the following:

- A. Flocculant Screening and Evaluation.
  - 1. Materials.
    - a. Ferric Arsenate Precipitate.
    - b. Ferrous Arsenate Precipitate.
  - 2. Determinations.
    - a. Examine the relative effectiveness of flocculants of varying charge, charge density and molecular weight.
- B. Static Thickening Studies.
  - 1. Materials.
    - a. Ferric Arsenate Precipitate.
    - b. Ferrous Arsenate Precipitate.

2. Determinations.

- a. Static thickening tests to examine flocculation, hydraulics, Unit Area requirements and the effect of feed solids concentration and to predict underflow solids concentration for conventional thickeners.

C. Pressure Filtration Studies.

1. Materials.

- a. Thickened Ferric Arsenate Precipitate.
- b. Thickened Ferrous Arsenate Precipitate.

2. Determinations.

- a. Pressure filtration tests to collect a general set of filtration data to design and size pressure filters.
  - i. Examine the effect of feed solids concentration, cake thickness and air blow duration on production rate and filter cake moisture.

D. Vacuum Filtration Studies.

1. Materials.

- a. Thickened Ferric Arsenate Precipitate.
- b. Thickened Ferrous Arsenate Precipitate.

2. Determinations.

- a. Vacuum filtration tests to collect a general set of filtration data to design and size vacuum filters.
  - i. Examine the effect of cake thickness and dry time on production rate and filter cake moisture.

E. Pulp Rheology Studies.

1. Material.

- a. Thickened Ferric Arsenate Precipitate.
  - b. Thickened Ferrous Arsenate Precipitate.
2. Determinations.
    - a. Rheology tests to determine the apparent viscosity of various process flow streams at known shear rates relative to solids concentration and temperature.

## **TEST EQUIPMENT**

### **GRAVITY SEDIMENTATION**

#### **Static Thickening Tests**

Static gravity sedimentation data were collected in two-liter graduated cylinders for sizing conventional thickeners.

Classical Kynch-type thickening tests were conducted in two-liter graduated cylinders. The aforementioned cylinders were fitted with slow turning picket rake mechanisms. Picket rakes serve to simulate the rake action found in full-scale thickeners in that they reorient floccule particle bridging and hydraulic channeling. Picket rakes also minimize the wall effects imparted by the narrow cylinder. In the two-liter tests, flocculant was added with a pipette which had an inverted stopper affixed to the delivery end to promote thorough mixing.

### **PRESSURE FILTRATION**

Filter press test work was performed using a pressure bomb device. The apparatus consisted of a 10 inch section of nominal 2 inch pipe, capped with two flanges. The upper flange contained fittings for air pressure connection and the sample feed port. The lower flange contained an integral drainage grid which supported the filter media. The filtrate port was centered in the bottom flange, below the filter media.

### **VACUUM FILTRATION**

The primary equipment required for vacuum filtration test work consists of a grid of known area covered with an appropriate filter cloth and surrounded by a metal or plastic shim to contain the pulp sample. This drainage grid or filter leaf was supported vertically on a vacuum flask. The differential pressure was translated from the vacuum pump to the filter leaf surface through large bore tubing, stainless steel nipples and a full-port ball valve. The vacuum pump was equipped with an internal bypass system which was used to control the vacuum level without the introduction of bleed air.

## **PULP RHEOLOGY**

### **Viscosity Tests**

Viscosity data were collected with the use of a Brookfield Model LVT rotating viscometer with cylindrical spindles.

The viscometer rotates a spindle and measures the torque required to overcome the viscous drag of the fluid by recording the point at which rotation begins. The immersed spindle is driven through a calibrated spring, which in turn is driven by a synchronous motor. The degree to which the spring compresses to overcome the viscous resistance is proportional to the viscosity of the fluid.

The defined geometry provided by cylindrical spindles facilitates calculation of shear stress and shear rate. The shear stress, a shear force across an area of contact is a function of the spindle dimensions and the torque developed by compression of the spring during rotation. The shear rate or velocity gradient is a function of the deformation properties of the fluid. For Newtonian fluids, the shear rate is proportional to rotational speed and spindle radius. However, since the apparent viscosity of non-Newtonian fluids changes with shear rate, the deformation properties of the fluid cannot be directly measured. A multiple number of apparent viscosities at specific shear rates are required to characterize non-Newtonian fluids.

## **TEST METHODS**

### **FLOCCULANT SCREENING**

Prior to conducting any sedimentation tests on the pulps listed above, flocculant screening tests were conducted on small samples of each to determine the relative effectiveness of each flocculant in areas such as floccule particle formation, the capture of fines, liquor release and the approximate dosage level required.

For the purpose of screening, each of the pulps was diluted, with the appropriate diluent, to a solids concentration likely to be encountered in thickener feed. The concentration of the various flocculants examined was 0.05 g/l active polyelectrolyte.

It is noted that the purpose of the screening tests conducted was not to determine the specific or optimum flocculant for usage in the plant, but rather, the purpose was to select the flocculant whose generic type would most likely be effective in plant operation, and therefore, suitable for solids/liquid separation testing.

## GRAVITY SEDIMENTATION

### Static Thickening Tests

The two-liter cylinder was filled to the appropriate mark with pulp known to yield a given (feed) solids concentration upon complete filling with dilute flocculant solution. Flocculation of the pulp was accomplished by adding the flocculant with the pipette/stopper arrangement described above.

Collected data consisted of pulp interface height as a function of time, flocculant concentration and dosage, temperature, pH, solids inventory within the cylinder and initial and final solids concentrations.

## PRESSURE FILTRATION

To produce a test filter cake in filter press tests, a given weight of pulp at the proper temperature and known to yield an approximate cake thickness was poured into the pressure chamber. The sample port was closed and air pressure applied above the feed slurry to facilitate initial cake formation and dewatering. As the last of the filtrate was produced, known by rapid air flow through the drainage grid, the form time ended, was noted and recorded, and the air blow (dry time) began.

At the end of the timed air blow period, the filter cake was discharged from the filter, and the wet weight and cake thickness were determined and recorded. After drying, the dry cake weight was recorded for cake moisture calculations.

## VACUUM FILTRATION

To produce a test filter cake, a given weight of flocculated/unflocculated pulp at the proper temperature and known to yield an approximate cake thickness was poured onto the upturned test leaf, while the ball valve connecting the leaf to the vacuum flask was simultaneously opened to apply the differential pressure. As the last of the liquid phase disappeared through the surface of the formed cake, the form time ended, and was noted, and the subsequent dry time began.

At the ended of the dry time, the filter cake was discharged from the leaf, and the wet weight and cake thickness were determined and recorded. After drying, the dry cake weight was recorded for cake moisture calculations.

## PULP RHEOLOGY

### Viscosity Tests

Multiple viscometer dial readings, over a range of spindle speeds, were taken from

pulp samples produced during gravity sedimentation testing. The initial dial reading was taken at a relatively low spindle speed. The speed was then incrementally increased until the dial reading exceeded 100. Dial readings are then generally taken through a decreasing progression of spindle speeds to examine the time dependent nature of fluids. The procedure is then repeated, if possible, with a second spindle size.

The inherent tendency of slurry suspensions to continue to settle during viscosity testing necessitates recording multiple dial readings at each spindle speed with gentle agitation of the pulp at each speed change. Hence, the time dependent nature of slurry suspensions cannot be examined.

## **DATA PRESENTATION AND DISCUSSION**

All collected and correlated data are recorded in the Appendix.

### **FLOCCULANT SCREENING**

Each flocculant under test was added in turn to samples of the appropriate pulp in a drop by drop fashion while gentle agitation was produced with a spatula. The amount of flocculant required to initiate floccule particle formation, or pinpoint floccule, was noted along with relevant notes as to the size of the floccules, the capture of fines, liquor release and the resultant supernatant quality and stability of the floccule structure.

Screening tests conducted on ferric arsenate and ferrous arsenate precipitates, as shown in Tables A and B, respectively, indicated that a medium to high molecular weight nonionic polymer, similar to Percol 351, should be employed to produce clear supernatant and rapidly settling particles.

### **GRAVITY SEDIMENTATION**

#### **Static Thickening Tests - Conventional Thickener Sizing**

Classical Kynch-type thickening tests were conducted for sizing conventional thickeners. Data collected from tests conducted on ferric and ferrous arsenate precipitates are summarized in Table C, in the Appendix.

#### **Ferric Arsenate Precipitate -- Conventional Thickener**

Gravity sedimentation data collected on ferric arsenate precipitate samples are recorded in Tables I - III and Figures 1 - 3, in the Appendix.

Tests were conducted at 1.5% and 2.2% feed solids with flocculant. The pH was 5.9 units.

Test data indicate that a conventional thickener should be sized based upon a Unit Area requirement of 38.0 ft<sup>2</sup>/STPD for the production of 8.0% solids underflow over the range of feed solids concentrations examined. The nonionic flocculant dosage will be 0.32 - 0.44 lbs/ST applied at a concentration less than 0.2 g/l (0.02%) with pulp in the range of pH 5.9 units.

#### Ferrous Arsenate Precipitate -- Conventional Thickener

Static cylinder test data collected on ferrous arsenate precipitate samples are recorded in Tables IV through VI and shown graphically in Figures 4 through 6, in the Appendix.

The tests were performed at feed solids concentrations of 1.2% and 2.0%, at pH 5.9 units, with flocculant.

Test data indicate that 8.0% solids underflow will be readily produced with a Unit Area requirement of 59.0 ft<sup>2</sup>/STPD with 0.40 - 0.48 lbs/ST nonionic flocculant. The feed solids concentration required to effect flocculation will be in the range of 1.2% - 2.0%.

### **FILTRATION**

#### Thickened Ferric Arsenate Precipitate -- Recessed Plate Filter Press

Recessed plate filter press sizing for thickened ferric arsenate precipitate is based on data displayed in Tables VII - VIIa; Figures 7a - 7d, in the Appendix.

Figure 7a indicates that a 1.0 inch dry filter cake weighs 1.94 lbs/ft<sup>2</sup>, hence, the dry bulk density is 23.28 lbs/ft<sup>3</sup>.

Figure 7b indicates that a 1.0 inch filter cake will form in 54.0 minutes.

Test work, as displayed in Figure 7c, demonstrates that the cake moisture content, at discharge from the recessed plate filter press, will be in the range of 69%. The corresponding wet bulk density will be 75.1 lbs/ft<sup>3</sup>.

Sizing of a recessed plate filter press will be limited by either the hydraulic rate requirement or the cake volume production requirement. In this instance, filter press sizing for thickened ferric arsenate precipitate is limited by the volume of cake to be produced.



### Recessed Plate Filter Press Design Summary

#### Thickened Ferric Arsenate Precipitate

Based on the production of thickener underflow at a solids concentration in the range of 4.8% - 8%, design of recessed plate filter presses for ferric arsenate precipitate should be based on the following:

#### Production Parameters

Material:	Thickened Ferric Arsenate Precipitate
Data Reference:	Tables VII - VIIa; Figures 7a - 7d
Sizing Reference:	Table VIII
Filter Feed Solids:	4.8% - 8.0%
Feed Temperature:	20°C
Feed Pressure:	80.0 psig

#### Design Parameters

Plate Size:	48" or 60"
Plate Recess:	1"
Cake Thickness:	2"
Cake Moisture:	69%
Wet Bulk Density:	75.1 lbs/ft <sup>3</sup> (@ 69% moisture)
Sizing Basis <sub>(1)</sub> :	107.4 ft <sup>3</sup> /ST (dry solids)

#### Note:

- (1) Filter press sizing basis in ft<sup>3</sup> of filter press volume per ST of dry solids. Sizing basis includes a 1.25 scale-up factor.

#### Thickened Ferrous Arsenate Precipitate

Based on the production of thickener underflow at a solids concentration in the range of 3.8% - 8%, design of recessed plate filter presses for ferrous arsenate precipitate should be based on the following:

#### Production Parameters

Material:	Thickened Ferrous Arsenate Precipitate
Data Reference:	Tables VIII - VIIIa; Figures 8a - 8d
Sizing Reference:	Table VIII

Filter Feed Solids:	3.8% - 8.0%
Feed Temperature:	20°C
Feed Pressure:	80.0 psig

#### Design Parameters

Plate Size:	48" or 60"
Plate Recess:	1"
Cake Thickness:	2"
Cake Moisture:	71%
Wet Bulk Density:	80.3 lbs/ft <sup>3</sup> (@ 71% moisture)
Sizing Basis <sub>(1)</sub> :	107.4 ft <sup>3</sup> /ST (dry solids)

#### Note:

- (1) Filter press sizing basis in ft<sup>3</sup> of filter press volume per ST of dry solids. Sizing basis includes a 1.25 scale-up factor.

#### Thickened Ferric Arsenate Precipitate -- Rotary Drum Vacuum Filters

Thickened ferric arsenate precipitate vacuum filtration test data and correlations are presented in Table IX and Figures 9a through 9c. Thickened ferrous arsenate precipitate vacuum filtration test data and correlations are presented in Table X and Figures 10a - 10c. A summary of rotary drum vacuum filter (scraper-type) operating and design parameters can be found in the Appendix as Tables IXi and Xi for ferric and ferrous arsenate precipitates, respectively.

For ferric arsenate, Figure 9a demonstrates the relationship between wet filter cake thickness, in inches, and dry filter cake weight,  $W$ , with units of dry lbs/ft<sup>2</sup>. The average dry bulk density, as shown by the correlation in Figure 9a, is 21.76 dry lbs/ft<sup>3</sup>. It is noted that for the purpose of design, an optimum cake thickness of 3/8 inch will be used. Accordingly, the unit weight of a 3/8 inch cake is 0.68 dry lbs/ft<sup>2</sup>.

For ferrous arsenate, Figure 10a demonstrates the relationship between wet filter cake thickness, in inches, and dry filter cake weight,  $W$ , with units of dry lbs/ft<sup>2</sup>. The average dry bulk density, as shown by the correlation in Figure 10a, is 19.84 dry lbs/ft<sup>3</sup>. It is noted that for the purpose of design, an optimum cake thickness of 3/8 inch will be used. Accordingly, the unit weight of a 3/8 inch cake is 0.62 dry lbs/ft<sup>2</sup>.

For ferric arsenate, Figure 9b displays the logarithmic relationship of dry cake weight,  $W$ , with units of dry lbs/ft<sup>2</sup>, as a function of cake formation time, in minutes. As predicted by theory, the slope of the curve is 1/2. The correlation shown in Figure 9b indicates that, at a vacuum level of 18 "Hg, a 3/8 inch cake will form, from 4.8% solids feed, in 14.2 minutes.

For ferrous arsenate, Figure 10b displays the logarithmic relationship of dry cake weight,  $W$ , with units of dry lbs/ft<sup>2</sup>, as a function of cake formation time, in minutes. As predicted by theory, the slope of the curve is  $\frac{1}{2}$ . The correlation shown in Figure 10b indicates that, at a vacuum level of 18 "Hg, a 3/8 inch cake will form, from 3.8% solids feed, in 23 minutes.

For ferric arsenate, the relationship between filter cake moisture at discharge and the dry time factor,  $\Theta_d/W$ , with units of min•ft<sup>2</sup>/lb is shown in Figure 9c.  $\Theta_d$  is the dry time in minutes, and  $W$  is the dry cake weight per unit area as inferred by dimensions given. The dry time factor permits a correlation between cake moisture and dry time by normalizing the dry time for cake weight and, hence, cake thickness. The correlation indicates that any dry time longer than 3.4 minutes will yield filter cake with 71.0% moisture due primarily to cake cracking.

For ferrous arsenate, the relationship between filter cake moisture at discharge and the dry time factor,  $\Theta_d/W$ , with units of min•ft<sup>2</sup>/lb is shown in Figure 10c.  $\Theta_d$  is the dry time in minutes, and  $W$  is the dry cake weight per unit area as inferred by dimensions given. The dry time factor permits a correlation between cake moisture and dry time by normalizing the dry time for cake weight and, hence, cake thickness. The correlation indicates that any dry time longer than 3.1 minutes will yield filter cake with 74.0% moisture due primarily to cake cracking.

#### Vacuum Filter Design Summary

The above specified and referenced correlations are used to size rotary drum vacuum filters as follows:

#### Thickened Ferric Arsenate Precipitate

#### Rotary Drum Vacuum Filter (scraper-type) Operating and Sizing Summary

Material:	Thickened Ferric Arsenate Precipitate
Data Reference:	Table IX and Figures 9a - 9c
Sizing Reference:	Table IXi
Filter Feed Solids:	4.8% - 8.0%
Feed Temperature:	20°C
Cake Thickness:	3/8 inch
Cake Moisture:	71.0%
Wet Bulk Density:	75.0 lbs/ft <sup>3</sup> (@ 71.0% moisture)
Production Rate <sub>(1,2)</sub> :	0.76 dry lbs/ft <sup>2</sup> •hr

Thickened Ferrous Arsenate Precipitate

Material:	Thickened Ferrous Arsenate Precipitate
Data Reference:	Table X and Figures 10a - 10c
Sizing Reference:	Table Xi
Filter Feed Solids:	3.8% - 8.0%
Feed Temperature:	20°C
Cake Thickness:	3/8 inch
Cake Moisture:	74.0%
Wet Bulk Density:	76.3 lbs/ft <sup>3</sup> (@ 74.0% moisture)
Production Rate <sub>(1,2)</sub> :	0.43 dry lbs/ft <sup>2</sup> •hr

Notes:

- (1) Production Rate includes a 0.8 scale-up factor.
- (2) Cycle Time and thus, Production Rate are form time limited.

**PULP RHEOLOGY**Viscosity Tests

Pulp viscosity data collected, using a Brookfield rotating viscometer, on thickened ferric and ferrous arsenate precipitates at 4.8% and 3.8% solids are recorded and displayed in Tables XI and XII; Figures 11 and 12, respectively.

Tests were performed to examine the rheological behavior and relationship between the apparent viscosity (cps) and shear rate (sec<sup>-1</sup>) of thickened iron arsenate precipitates at anticipated thickener underflow solids concentrations. The correlations of apparent viscosity with shear rate, for the samples examined, are shown in Figures 11 and 12, in the Appendix.

The apparent viscosity exhibited by a pulp at a specific shear rate can be due, in part, to solids concentration, mineralogical or chemical composition, temperature, flocculant dosage and concentration and pH.

The apparent viscosity of thickener underflow pulp is affected, in large part, by chemical composition, as indicated by comparing Figures 11 and 12. At a reference shear rate of 25 sec<sup>-1</sup>, the apparent viscosity of the Iron (III) arsenate at 4.8% solids is 32 cps, while the Iron (II) arsenate at 3.8% solids exhibits an apparent viscosity of 50 cps.

The influence of pH and chemical composition on viscosity can be masked by other process conditions such as flocculant dosage, which is typically a primary factor influencing the apparent viscosity of thickener underflow pulp once over-dose conditions are met.

The decreasing apparent viscosity with increasing shear rate or "shear thinning" behavior of the pulps examined is characteristic of the pseudoplastic class of non-Newtonian fluids. It demonstrates the need to achieve and maintain a specific velocity gradient or shear rate in thickener underflow lines in order to initiate and maintain flow. The shear rate required to initiate flow will increase with an increasing underflow solids concentrations or flocculant dosage.

### SUMMARY AND RECOMMENDATIONS

Test work conducted on Hazen Research Inc., Project #8068, process flow streams, as described in the above report, supports the following conclusions:

1. A medium to high molecular weight nonionic polyacrylamide flocculant can be used to enhance the settling characteristics of either the ferric or ferrous arsenate precipitates.
2. Design of a conventional thickener for duty on *ferric arsenate precipitate* should be based on the following criteria:
  - a. Unit Area requirement of 38.0 ft<sup>2</sup>/STPD for the production of 8% solids underflow.
  - b. Feed solids concentration of 1.5% - 2.2%, at pH 5.9.
  - c. Nonionic flocculant dosage in the range of 0.32-0.44 lbs/ST.
3. Design of a conventional thickener for duty on *ferrous arsenate precipitate* should be based on the following criteria:
  - a. Unit Area requirement of 59.0 ft<sup>2</sup>/STPD for the production of 8% solids underflow.
  - b. Feed solids concentration of 1.2% - 2.0%, at pH 5.9.
  - c. Nonionic flocculant dosage in the range of 0.40-0.48 lbs/ST.

4. Sizing of recessed plate filter presses to dewater *ferric arsenate precipitate* should be based on the following design criteria:

Thickened (Ferric) Precipitate

Filter Feed Solids:	4.8 - 8.0%
Cake Thickness:	2.0 inches
Cake Moisture:	69%
Wet Bulk Density:	75.1 lbs/ft <sup>3</sup>
Sizing Basis:	107.4 ft <sup>3</sup> /ST (dry solids)

5. Sizing of recessed plate filter presses to dewater *ferrous arsenate precipitate* should be based on the following design criteria:

Thickened (Ferrous) Precipitate

Filter Feed Solids:	3.8 - 8.0%
Cake Thickness:	2.0 inches
Cake Moisture:	71%
Wet Bulk Density:	80.3 lbs/ft <sup>3</sup>
Sizing Basis:	107.4 ft <sup>3</sup> /ST (dry solids)

6. Sizing of rotary drum vacuum filters (scraper-type) to dewater *ferric arsenate precipitate* can be based on the following design criteria:

Thickened (Ferric) Precipitate

Filter Feed Solids:	4.8 - 8.0%
Cake Thickness:	3/8 inch
Cake Moisture:	71.0%
Wet Bulk Density:	75.0 lbs/ft <sup>3</sup>
Production Rate:	0.76 dry lbs/ft <sup>2</sup> •hr

7. Sizing of rotary drum vacuum filters (scraper-type) to dewater *ferrous arsenate precipitate* can be based on the following design criteria:

Thickened (Ferrous) Precipitate

Filter Feed Solids:	3.8 - 8.0%
Cake Thickness:	3/8 inch
Cake Moisture:	74.0%
Wet Bulk Density:	76.3 lbs/ft <sup>3</sup>
Production Rate:	0.43 dry lbs/ft <sup>2</sup> •hr

8. The oxidation state of iron, ferric or ferrous, is the primary factor influencing the apparent viscosity of the arsenate precipitate thickener underflow pulp, with the Iron (II) specie being the most viscous. However, unless over-flocculation is practiced, no pumping, mixing or pulp transport problems are anticipated.

008458

## APPENDIX B



**TABLE A**  
**FLOCCULANT SCREENING SERIES**

Hazen Research Inc.  
 Arsenic Removal Project

Material: Ferric Arsenate Precipitate  
 Flocculant Sol'n: All Solutions @ 0.05 g/l  
 Solids S.G.: 3.18  
 % Solids to Test: 1.5  
 pH: 5.9 Units  
 Temperature: 20 °C

Floc Added, mls	0.5	1.0	2.0	3.0	4.0	5.0	7.5	10.0
Approx. Dosage, lbs/ST	0.042	0.085	0.169	0.254	0.339	0.424	0.636	0.847

**PRODUCT: % Chg<sub>(1)</sub>**

AC 455	5	CAT	M	MH	H*	H	VH	VH	VH	VH
AC 351	0	NON	MH	H*	VH	VH	VH	VH	VH	VH
AC E24	10	AN	M	MH	H*	H	VH	VH	VH	VH
AC 155	20	AN	MH	H*	H	VH	VH	VH	VH	VH
AC 1011	30	AN	MH	H*	H	VH	VH	VH	VH	VH
AC 156	40	AN	M	MH	H*	VH	VH	VH	VH	VH

**NOTES:**

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

**KEY TO NOTATION:**

PP	Pin Point Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
*	Clarity Achieved.		
AN	Anionic Flocculant.		
NON	Nonionic Flocculant.		
CAT	Cationic Flocculant.		

**TABLE B**  
**FLOCCULANT SCREENING SERIES**

Hazen Research Inc.  
Arsenic Removal Project

Material: Ferrous Arsenate Precipitate  
Flocculant Sol'n: All Solutions @ 0.05 g/l  
Solids S.G.: 3.18  
% Solids to Test: 1.2  
pH: 5.9 Units  
Temperature: 20 °C

Floc Added, mls	0.5	1.0	2.0	3.0	4.0	5.0	7.5	10.0
Approx. Dosage, lbs/ST	0.054	0.108	0.215	0.323	0.430	0.538	0.806	1.075

**PRODUCT: % Chg<sub>(1)</sub>**

AC 455	5	CAT	M	MH	H	H*	H	H	VH	VH
AC 351	0	NON	MH	H	H*	VH	VH	VH	VH	VH
AC E24	10	AN	M	MH	H	H*	VH	VH	VH	VH
AC 155	20	AN	H	H	VH*	VH	VH	VH	VH	VH
AC 1011	30	AN	MH	H	H*	VH	VH	VH	VH	VH
AC 156	40	AN	M	MH	H	H*	VH	VH	VH	VH

**NOTES:**

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

**KEY TO NOTATION:**

PP	Pin Point Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
*	Clarity Achieved.		
AN	Anionic Flocculant.		
NON	Nonionic Flocculant.		
CAT	Cationic Flocculant.		

**TABLE C**  
**STATIC THICKENING DATA SUMMARY**

Hazen Research Inc.  
Arsenic Removal Project

TEST NO.	FEED % D.S./pH	MAT'L <sup>(1)</sup>	FLOC <sup>(2)</sup> lbs/ST	H.L. <sup>(3)</sup>	UNIT AREA <sup>(4)</sup> ft <sup>2</sup> /STPD @ UF			
					6%	7%	8%	10%
1	1.5/5.9	Ferric	0.162	0.38	30.98		42.97	50.16
2	1.5/5.9	Ferric	0.324	0.42	26.09		36.93	43.44
3	2.2/5.9	Ferric	0.443	0.21	23.41		37.53	46.00
4	1.2/5.9	Ferrous	0.202	0.33	53.19	59.78	64.73	
5	1.2/5.9	Ferrous	0.403	0.42	45.52	52.24	57.28	
6	2.0/5.9	Ferrous	0.484	0.13	46.09	53.35	58.80	

**NOTES:**

- (1) Ferric: Ferric Arsenate Precipitate  
Ferrous: Ferrous Arsenate Precipitate

- (2) FLOC:

Tests 1 - 6: Allied Colloids Percol 351, a medium to high molecular weight nonionic polyacrylamide was used for ferric and ferrous arsenate precipitates. Other products meeting the same description would also serve.

- (3) Hydraulic Loading or Rise Rate (gpm/ft<sup>2</sup>) includes a 0.5 scale-up factor.  
(4) Unit Area (ft<sup>2</sup>/STPD) includes a 1.25 scale-up factor.

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008462

Company: Hazen Research Inc  
Arsenic Removal Project

Table No.: 1  
Test No.: 1  
Test Date: July 26, 1991  
By: ST  
Location: HRI Labs

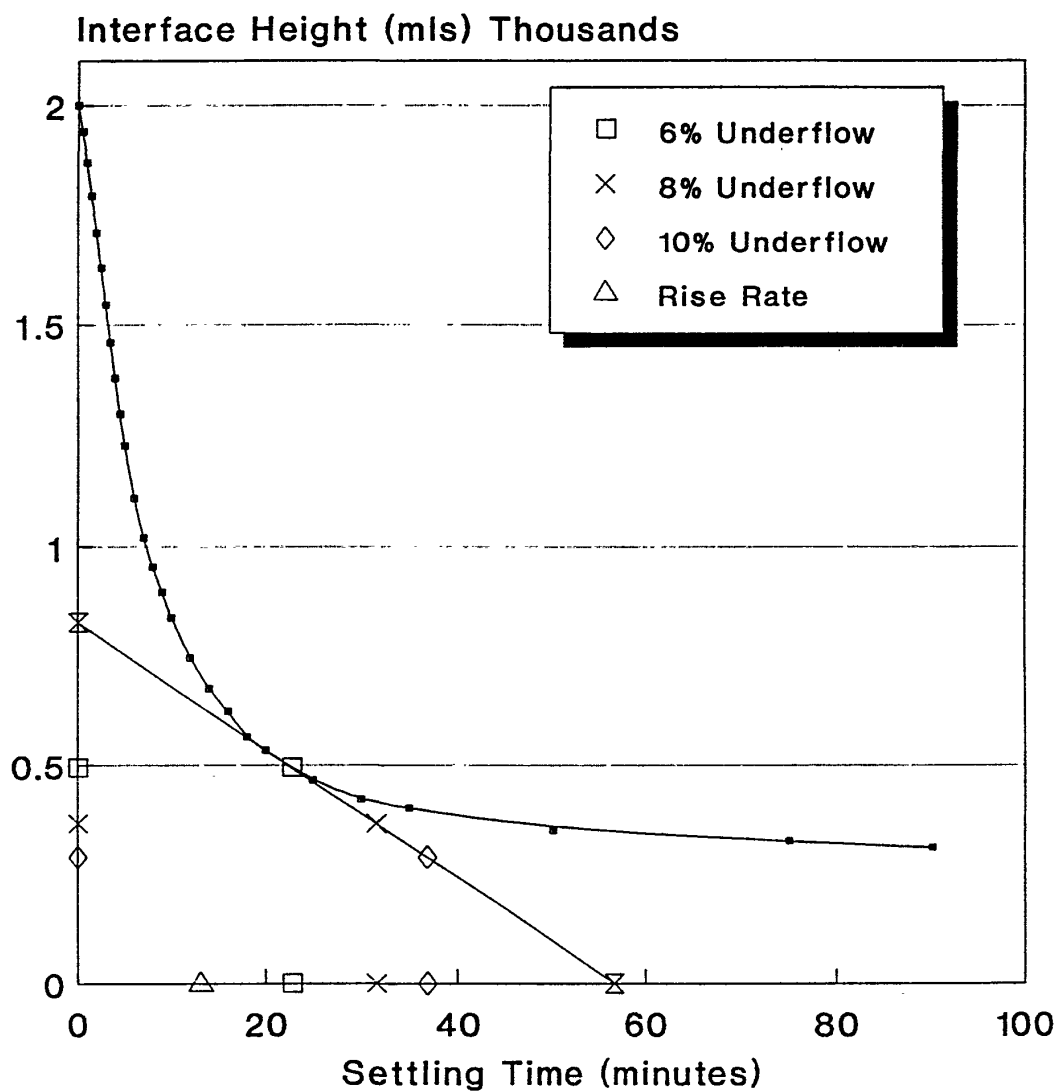
Material: 1.5 % Solids Consisting of FERRIC Arsenate Precipitate  
98.5 % Liquids Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

Floc. Dosage: 0.162 lbs/ST		SETTLING DATA		
pH: 5.9 Units				
Temperature: 20 °C				
		Time (min)	Interface Height (mls)	Average Percent Solids
Flocculant: Percol 351		0	2000	1.53
Type: Nonionic		0.5	1940	1.58
Concentration: 0.10 g/l		1	1870	1.63
Mls Added: 25 mls		1.5	1795	1.70
Picket Speed: 6 rph		2	1710	1.78
		2.5	1630	1.87
Description: Clear Supernatant;		3	1545	1.97
Very Heavy Floc. Structure.		3.5	1460	2.09
		4	1380	2.21
Underflow Measurements:		4.5	1300	2.34
Undecanted Volume: 2000 mls		5	1230	2.47
Slurry & Tare: 3137.3 gms		6	1110	2.73
Cylinder Weight: 1100.0 gms		7	1020	2.97
Slurry Weight: 2037.3 gms		8	953	3.17
Dry Solids Weight: 30.9 gms		9	895	3.37
Supernatant S.G. 1.0		10	837	3.60
Solids S.G. 3.2		12	745	4.03
		14	675	4.44
Settling Vessel Size: 1510 mls/ft		16	623	4.80
		18	565	5.27
Ho= 1.32 ft ( 0.404 m)		20	535	5.56
Co= 4.82E-04 ST/ft <sup>3</sup> ( 1.55E-02 MT/m <sup>3</sup> )		25	465	6.36
		30	420	7.00
Tu = 1.58E-02 days at 6 % u'flow		35	400	7.34
Tu = 2.20E-02 days at 8 % u'flow		50	350	8.32
Tu = 2.56E-02 days at 10 % u'flow		75	325	8.93
		90	310	9.33
Unit Area at: 6 % u'flow= 30.98 ft <sup>2</sup> /STPD (		3.173	m <sup>2</sup> /MTPD)	
Unit Area at: 8 % u'flow= 42.97 ft <sup>2</sup> /STPD (		4.400	m <sup>2</sup> /MTPD)	
Unit Area at: 10 % u'flow= 50.16 ft <sup>2</sup> /STPD (		5.136	m <sup>2</sup> /MTPD)	
Note: Unit Area Includes a 1.25 Scale-Up Factor.				
Rise Rate = 0.38 gpm/ft <sup>2</sup> (		0.926	m <sup>3</sup> /(hr*m <sup>2</sup> ))	
Note: Rise Rate Includes a 0.5 Scale-Up Factor.				

FIG. 1: INTERFACE HT. vs. SETTLING TIME

Hazen Research Inc.  
Arsenic Removal Project



Material: Ferric Arsenate Precipitate  
Feed Solids: 1.5% pH: 5.9 Units  
Floc. Dosage: 0.162 lbs/ST

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research Inc  
Arsenic Removal Project

Table No.: II  
Test No.: 2  
Test Date: July 26, 1993  
By: ST  
Location: HRI Labs

008464

Material: 1.5 % Solids Consisting of FERRIC Arsenate Precipitate  
98.5 % Liquids Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

Floc. Dosage:	0.324 lbs/ST	<b>SETTLING DATA</b>		
pH:	5.9 Units		Interface	Average
Temperature:	20 °C	Time	Height	Percent
		(min)	(mls)	Solids
Flocculant:	Percol 351	0	2000	1.53
Type:	Nonionic	0.5	1920	1.59
Concentration:	0.20 g/l	1	1840	1.66
Mls Added:	25 mls	1.5	1750	1.74
Picket Speed:	6 rph	2	1660	1.84
		2.5	1575	1.94
Description:	Clear Supernatant;	3	1480	2.06
	Very Heavy Floc. Structure.	3.5	1380	2.21
		4	1295	2.35
Underflow Measurements:		4.5	1217	2.50
Undecanted Volume:	2000 mls	5	1153	2.63
Slurry & Tare:	3144.3 gms	6	1045	2.90
Cylinder Weight:	1107.0 gms	7	960	3.15
Slurry Weight:	2037.3 gms	8	875	3.45
Dry Solids Weight:	30.9 gms	9	805	3.74
Supernatant S.G.	1.0	10	737	4.08
Solids S.G.	3.2	12	645	4.64
		14	585	5.10
Settling Vessel Size:	1540 mls/ft	16	540	5.51
	5052 mls/m	18	505	5.87
Ho = 1.30 ft (0.396 m)		20	480	6.17
Co = 4.82E-04 ST/ft <sup>3</sup> (1.55E-02 MT/m <sup>3</sup> )		25	435	6.77
		30	400	7.34
Tu = 1.31E-02 days at 6 % u'flow		35	380	7.70
Tu = 1.85E-02 days at 8 % u'flow		50	340	8.56
Tu = 2.18E-02 days at 10 % u'flow		75	300	9.62
		90	285	10.09
Unit Area at: 6 % u'flow = 26.09 ft <sup>2</sup> /STPD (		2.672	m <sup>2</sup> /MTPD)	
Unit Area at: 8 % u'flow = 36.93 ft <sup>2</sup> /STPD (		3.782	m <sup>2</sup> /MTPD)	
Unit Area at: 10 % u'flow = 43.44 ft <sup>2</sup> /STPD (		4.448	m <sup>2</sup> /MTPD)	

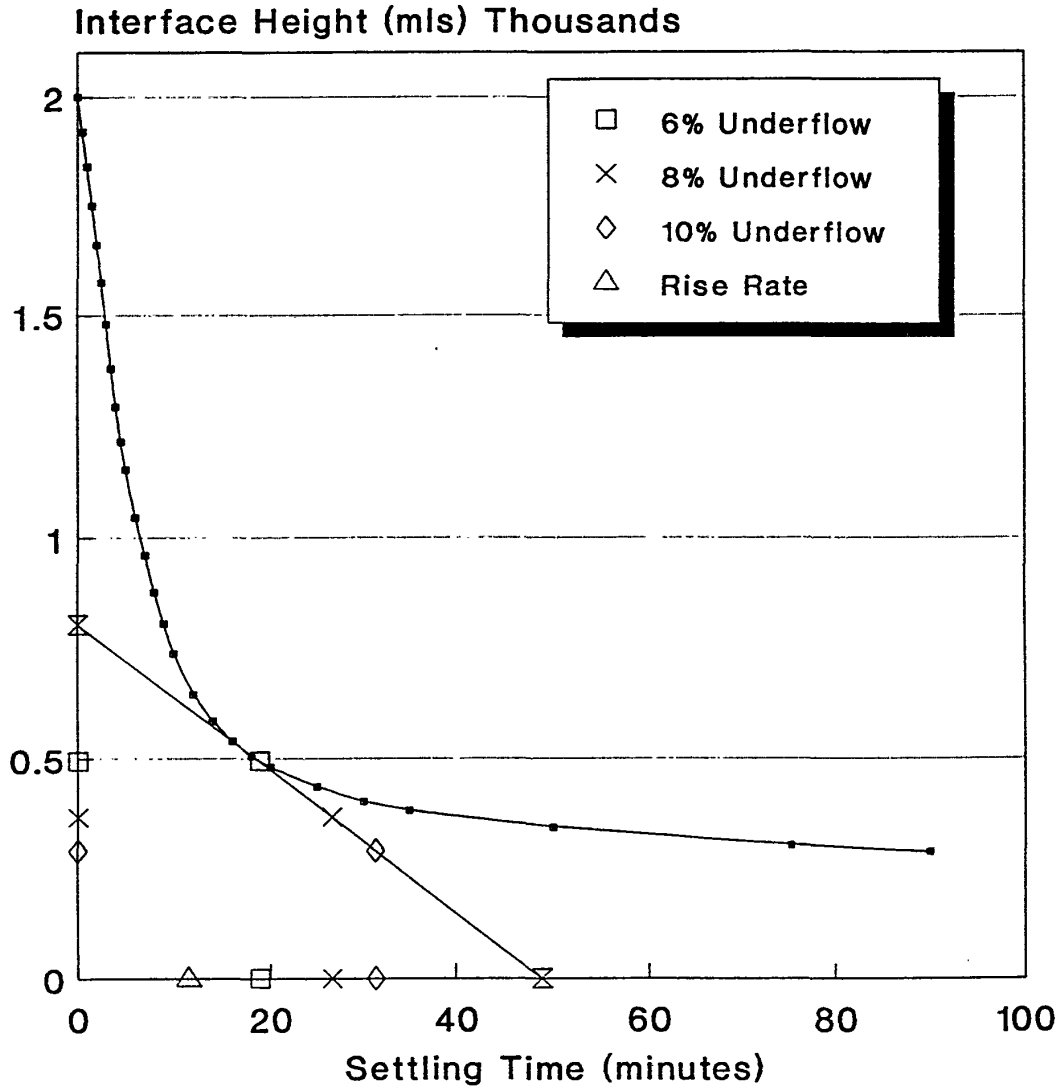
Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 0.42 gpm/ft<sup>2</sup> ( 1.039 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 2: INTERFACE HT. vs. SETTLING TIME**

Hazen Research Inc.  
Arsenic Removal Project



Material: Ferric Arsenate Precipitate  
Feed Solids: 1.5% pH: 5.9 Units  
Floc. Dosage: 0.324 lbs/ST

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008466

Company: Hazen Research Inc  
Arsenic Removal Project

Table No.: III  
Test No.: 3  
Test Date: July 26, 1993  
By: ST  
Location: HRI Labs

Material: 2.2 % Solids Consisting of FERRIC Arsenate Precipitate  
97.8 % Liquids Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

Floc. Dosage:	0.443 lbs/ST	<b>SETTLING DATA</b>		
pH:	5.9 Units		Interface	Average
Temperature:	20 °C	Time	Height	Percent
		(min)	(mls)	Solids
Flocculant:	Percol 351	0	2000	2.22
Type:	Nonionic	0.5	1967	2.26
Concentration:	0.20 g/l	1	1937	2.29
Mls Added:	50 mls	1.5	1900	2.34
Picket Speed:	6 rph	2	1857	2.39
		2.5	1807	2.45
Description:	Clear Supernatant;	3	1770	2.50
	Heavy Floc. Structure.	3.5	1720	2.58
		4	1665	2.66
Underflow Measurements:		5	1580	2.80
Undecanted Volume:	2000 mls	6	1495	2.96
Slurry & Tare:	3146.6 gms	7	1390	3.17
Cylinder Weight:	1100.0 gms	8	1295	3.40
Slurry Weight:	2046.6 gms	9	1220	3.61
Dry Solids Weight:	45.1 gms	10	1145	3.84
Supernatant S.G.	1.0	12.5	1015	4.31
Solids S.G.	3.2	15	905	4.82
		17.5	832	5.23
Settling Vessel Size:	1510 mls/ft	20	780	5.56
	4954 mls/m	25	717	6.03
Ho = 1.32 ft ( 0.404 m)		30	657	6.56
Co = 7.04E-04 ST/ft <sup>3</sup> ( 2.26E-02 MT/m <sup>3</sup> )		35	625	6.88
		40	602	7.13
Tu = 1.75E-02 days at 6 % u'flow		50	570	7.51
Tu = 2.80E-02 days at 8 % u'flow		60	555	7.70
Tu = 3.43E-02 days at 10 % u'flow		75	520	8.19
		90	500	8.49
Unit Area at: 6 % u'flow =	23.41 ft <sup>2</sup> /STPD (	2.398	m <sup>2</sup> /MTPD)	
Unit Area at: 8 % u'flow =	37.53 ft <sup>2</sup> /STPD (	3.843	m <sup>2</sup> /MTPD)	
Unit Area at: 10 % u'flow =	46.00 ft <sup>2</sup> /STPD (	4.711	m <sup>2</sup> /MTPD)	

Note: Unit Area Includes a 1.25 Scale-Up Factor.

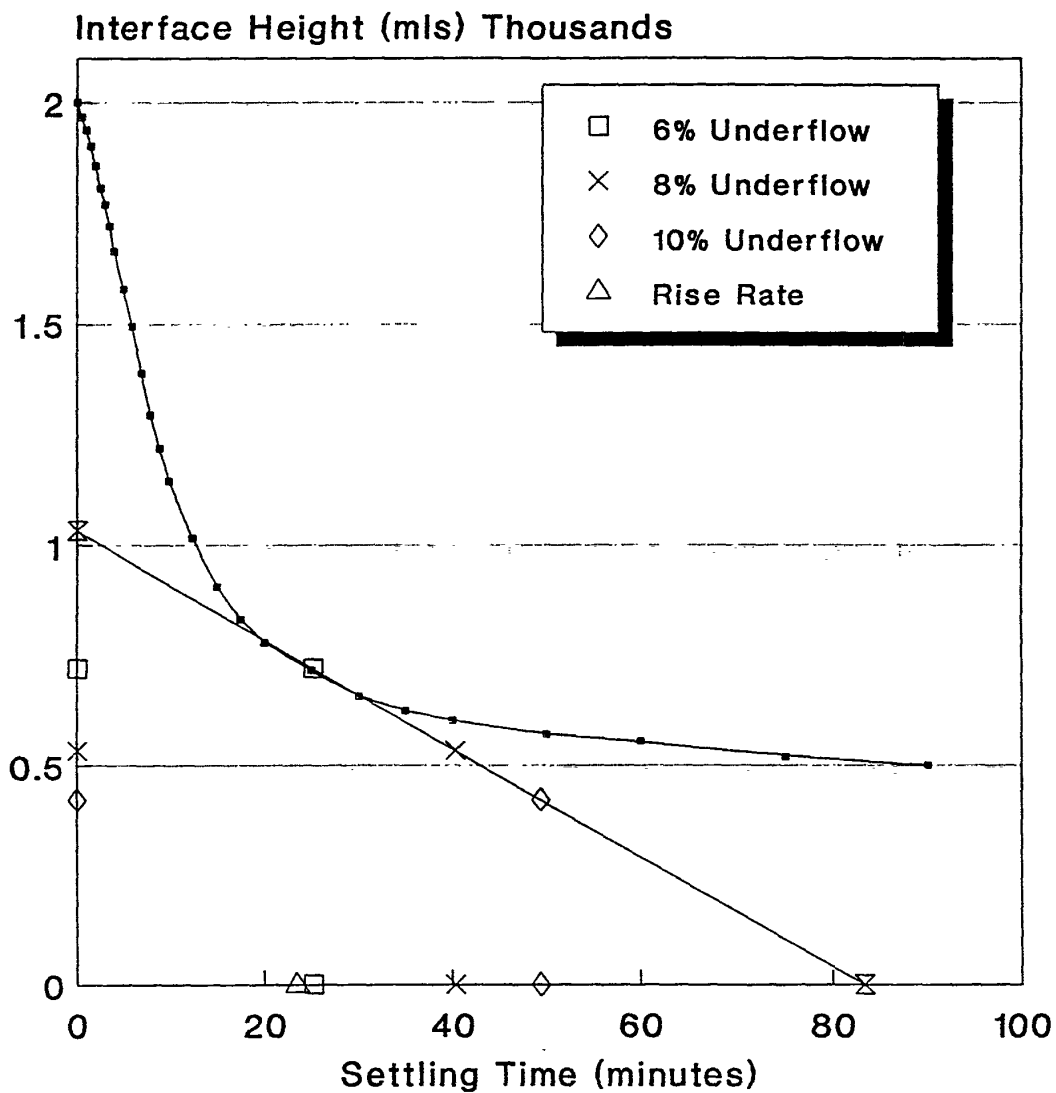
Rise Rate = 0.21 gpm/ft<sup>2</sup> ( 0.517 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.



FIG. 3: INTERFACE HT. vs. SETTLING TIME

Hazen Research Inc.  
Arsenic Removal Project



Material: Ferric Arsenate Precipitate  
Feed Solids: 2.2% pH: 5.9 Units  
Floc. Dosage: 0.443 lbs/ST

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research Inc  
Arsenic Removal Project

Table No.: IV  
Test No.: 4  
Test Date: July 26, 1993  
By: ST  
Location: HRI Labs

008468

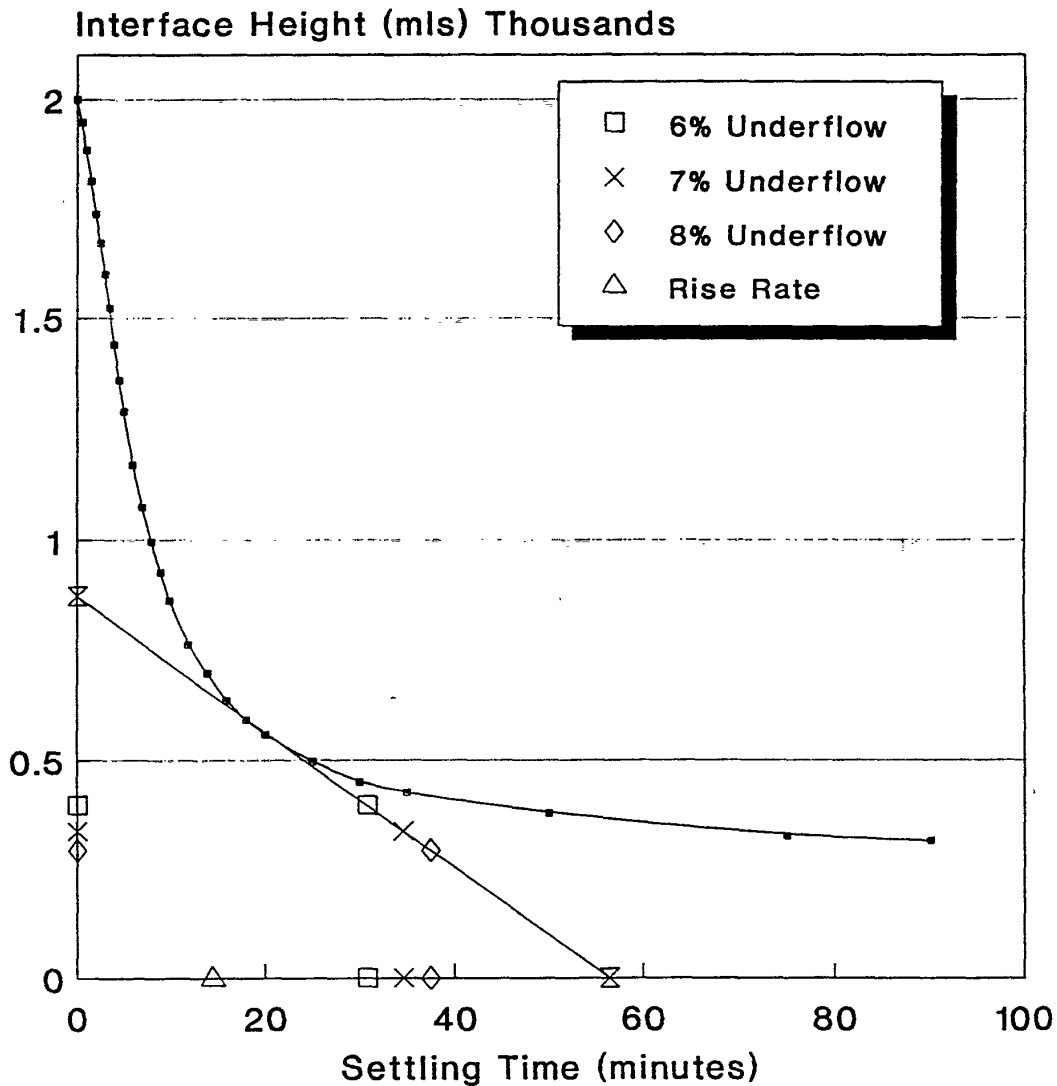
Material: 1.2 % Solids Consisting of FERROUS Arsenate Precipitate  
98.8 % Liquids Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

Floc. Dosage:	0.202 lbs/ST	<b>SETTLING DATA</b>		
pH:	5.9 Units		Interface	Average
Temperature:	20 °C	Time	Height	Percent
		(min)	(mls)	Solids
Flocculant:	Percol 351	0	2000	1.23
Type:	Nonionic	0.5	1947	1.26
Concentration:	0.10 g/l	1	1885	1.30
Mls Added:	25 mls	1.5	1815	1.35
Picket Speed:	6 rph	2	1740	1.41
		2.5	1672	1.47
Description:	Clear Supernatant;	3	1600	1.53
	Very Heavy Floc. Structure.	3.5	1522	1.61
		4	1440	1.70
Underflow Measurements:		4.5	1360	1.80
Undecanted Volume:	2000 mls	5	1290	1.90
Slurry & Tare:	3147.0 gms	6	1170	2.09
Cylinder Weight:	1107.0 gms	7	1075	2.27
Slurry Weight:	2040.0 gms	8	995	2.45
Dry Solids Weight:	24.8 gms	9	925	2.63
Supernatant S.G.	1.0	10	860	2.83
Solids S.G.	3.2	12	760	3.19
		14	697	3.47
Settling Vessel Size:	1540 mls/ft	16	635	3.80
	5052 mls/m	18	592	4.07
Ho=	1.30 ft ( 0.396 m)	20	557	4.32
Co=	3.87E-04 ST/ft <sup>3</sup> ( 1.24E-02 MT/m <sup>3</sup> )	25	497	4.82
		30	450	5.31
Tu =	2.14E-02 days at 6 % u'flow	35	425	5.61
Tu =	2.40E-02 days at 7 % u'flow	50	377	6.29
Tu =	2.60E-02 days at 8 % u'flow	75	325	7.25
		90	315	7.47
Unit Area at:	6 % u'flow= 53.19 ft <sup>2</sup> /STPD (	5.447	m <sup>2</sup> /MTPD)	
Unit Area at:	7 % u'flow= 59.78 ft <sup>2</sup> /STPD (	6.122	m <sup>2</sup> /MTPD)	
Unit Area at:	8 % u'flow= 64.73 ft <sup>2</sup> /STPD (	6.629	m <sup>2</sup> /MTPD)	
Note: Unit Area Includes a 1.25 Scale-Up Factor.				
Rise Rate =	0.33 gpm/ft <sup>2</sup> (	0.818	m <sup>3</sup> /(hr*m <sup>2</sup> ))	
Note: Rise Rate Includes a 0.5 Scale-Up Factor.				

FIG. 4: INTERFACE HT. vs. SETTLING TIME

Hazen Research Inc.  
Arsenic Removal Project



Material: Ferrous Arsenate Precipitate  
Feed Solids: 1.2% pH: 5.9 Units  
Floc. Dosage: 0.202 lbs/ST

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research Inc  
Arsenic Removal Project

Table No.: V  
Test No.: 5  
Test Date: July 26, 199  
By: ST  
Location: HRI Labs

008470

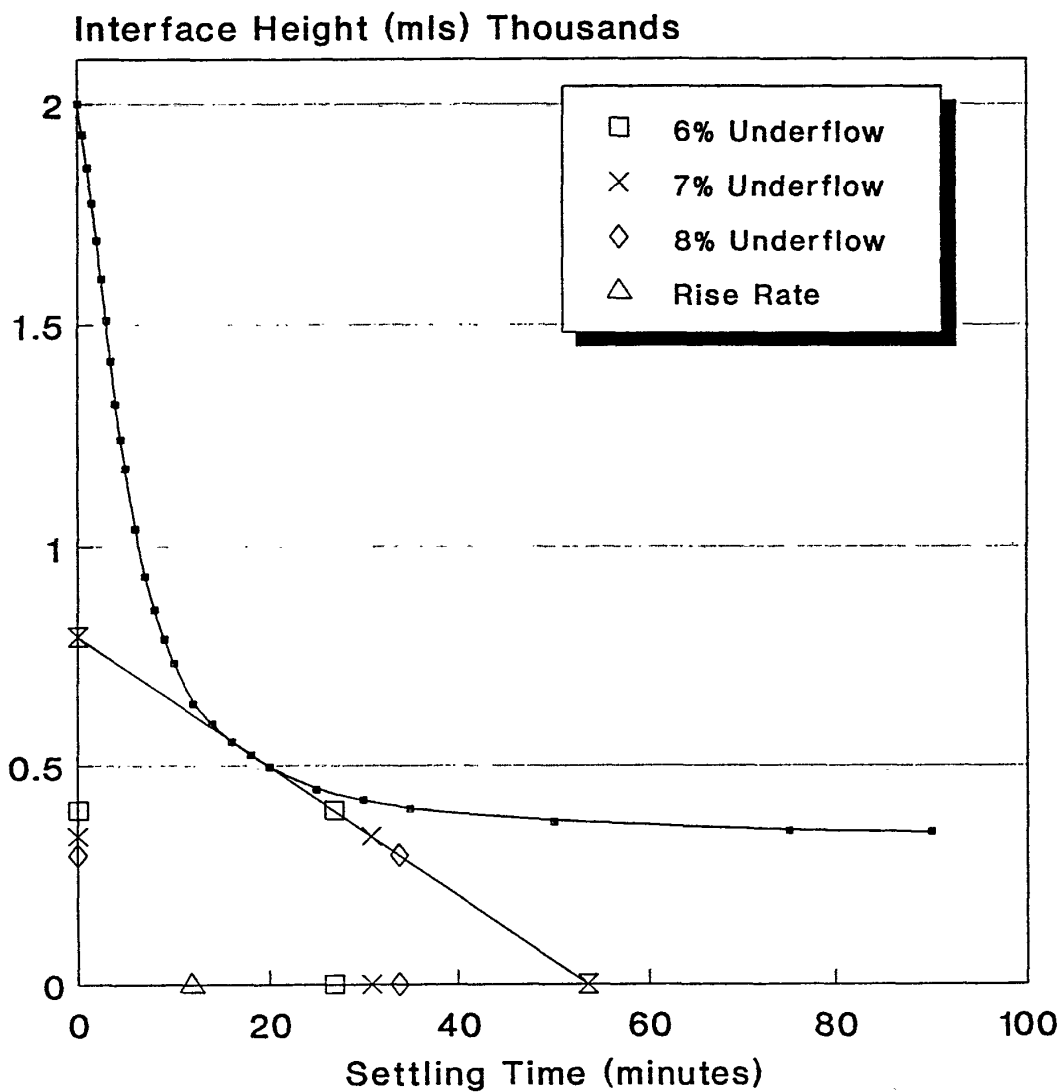
Material: 1.2 % Solids Consisting of FERROUS Arsenate Precipitate  
98.8 % Liquids Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

Floc. Dosage:	0.403 lbs/ST	<b>SETTLING DATA</b>		
pH:	5.9 Units		Interface	Average
Temperature:	20 °C	Time	Height	Percent
		(min)	(mls)	Solids
Flocculant:	Percol 351	0	2000	1.23
Type:	Nonionic	0.5	1930	1.27
Concentration:	0.20 g/l	1	1855	1.32
Mls Added:	25 mls	1.5	1775	1.38
Picket Speed:	6 rph	2	1690	1.45
		2.5	1602	1.53
Description:	Clear Supernatant;	3	1510	1.62
	Very Heavy Floc. Structure.	3.5	1417	1.73
		4	1322	1.85
Underflow Measurements:		4.5	1242	1.97
Undecanted Volume:	2000 mls	5	1177	2.08
Slurry & Tare:	3140.0 gms	6	1040	2.35
Cylinder Weight:	1100.0 gms	7	932	2.61
Slurry Weight:	2040.0 gms	8	855	2.84
Dry Solids Weight:	24.8 gms	9	790	3.07
Supernatant S.G.	1.0	10	735	3.30
Solids S.G.	3.2	12	642	3.76
		14	597	4.04
Settling Vessel Size:	1510 mls/ft	16	555	4.34
	4954 mls/m	18	525	4.58
Ho= 1.32 ft ( 0.404 m)		20	497	4.82
Co= 3.87E-04 ST/ft <sup>3</sup> ( 1.24E-02 MT/m <sup>3</sup> )		25	445	5.37
		30	420	5.68
Tu = 1.87E-02 days at 6 % u'flow		35	400	5.95
Tu = 2.14E-02 days at 7 % u'flow		50	370	6.41
Tu = 2.35E-02 days at 8 % u'flow		75	350	6.76
		90	347	6.81
Unit Area at: 6 % u'flow=	45.52 ft <sup>2</sup> /STPD (	4.662	m <sup>2</sup> /MTPD)	
Unit Area at: 7 % u'flow=	52.24 ft <sup>2</sup> /STPD (	5.350	m <sup>2</sup> /MTPD)	
Unit Area at: 8 % u'flow=	57.28 ft <sup>2</sup> /STPD (	5.866	m <sup>2</sup> /MTPD)	
Note: Unit Area Includes a 1.25 Scale-Up Factor.				
Rise Rate =	0.42 gpm/ft <sup>2</sup> (	1.026	m <sup>3</sup> /(hr*m <sup>2</sup> ))	
Note: Rise Rate Includes a 0.5 Scale-Up Factor.				

FIG. 5: INTERFACE HT. vs. SETTLING TIME

Hazen Research Inc.  
Arsenic Removal Project



Material: Ferrous Arsenate Precipitate  
Feed Solids: 1.2% pH: 5.9 Units  
Floc. Dosage: 0.403 lbs/ST

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research Inc  
Arsenic Removal Project

Table No.: VI  
Test No.: 6  
Test Date: July 26, 1991  
By: ST  
Location: HRI Labs

008472

Material: 2.0 % Solids Consisting of FERROUS Arsenate Precipitate  
98.0 % Liquids Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

Floc. Dosage: 0.484 lbs/ST  
pH: 5.9 Units  
Temperature: 20 °C

**SETTLING DATA**

Time (min)	Interface Height (mls)	Average Percent Solids
---------------	------------------------------	------------------------------

Flocculant: Percol 351  
Type: Nonionic  
Concentration: 0.20 g/l  
Mls Added: 50 mls  
Picket Speed: 6 rph

0	2000	2.04
0.5	1985	2.05
1	1960	2.08
1.5	1935	2.10
2	1917	2.12
2.5	1898	2.14
3	1877	2.17
3.5	1850	2.20
4	1822	2.23
4.5	1790	2.27
5	1760	2.31
6	1682	2.41
7	1627	2.49
8	1565	2.59
9	1517	2.67
10	1457	2.78
12.5	1315	3.07
15	1180	3.42
17.5	1080	3.73
20	1010	3.98
25	927	4.32
30	860	4.65
35	820	4.87
40	790	5.05
50	745	5.34
60	710	5.59
90	640	6.18

Description: Clear Supernatant;  
Heavy Floc. Structure.

**Underflow Measurements:**

Undecanted Volume: 2000 mls  
Slurry & Tare: 3154.3 gms  
Cylinder Weight: 1107.0 gms  
Slurry Weight: 2047.3 gms  
Dry Solids Weight: 41.3 gms  
Supernatant S.G.: 1.0  
Solids S.G.: 3.2

**Settling Vessel Size:**

1540 mls/ft  
5052 mls/m  
Ho = 1.30 ft ( 0.396 m)  
Co = 6.45E-04 ST/ft<sup>3</sup> ( 2.07E-02 MT/m<sup>3</sup>)  
Tu = 3.09E-02 days at 6 % u'flow  
Tu = 3.57E-02 days at 7 % u'flow  
Tu = 3.94E-02 days at 8 % u'flow

Unit Area at: 6 % u'flow = 46.09 ft<sup>2</sup>/STPD ( 4.720 m<sup>2</sup>/MTPD)  
Unit Area at: 7 % u'flow = 53.35 ft<sup>2</sup>/STPD ( 5.464 m<sup>2</sup>/MTPD)  
Unit Area at: 8 % u'flow = 58.80 ft<sup>2</sup>/STPD ( 6.022 m<sup>2</sup>/MTPD)

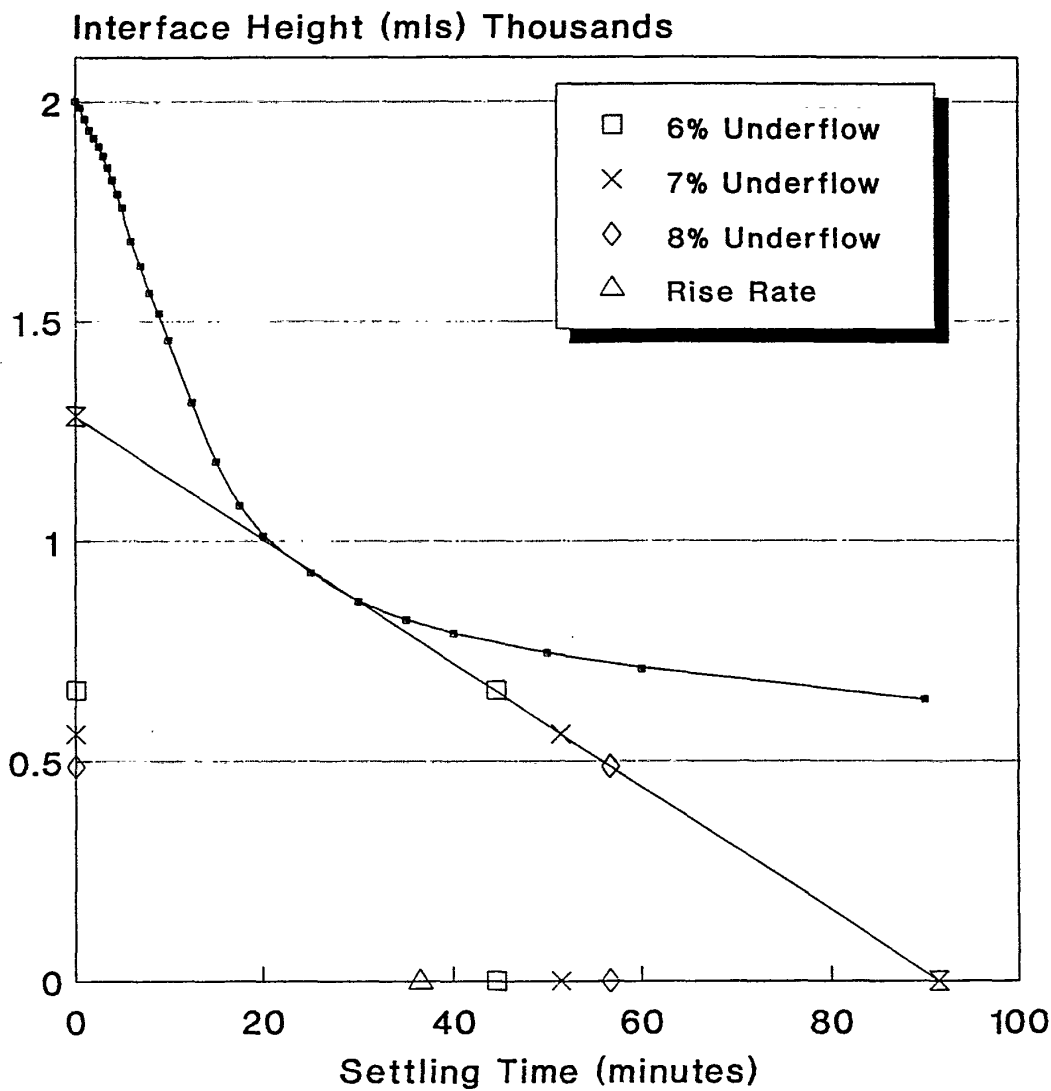
Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 0.13 gpm/ft<sup>2</sup> ( 0.325 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 6: INTERFACE HT. vs. SETTLING TIME

Hazen Research Inc.  
Arsenic Removal Project



Material: Ferrous Arsenate Precipitate  
Feed Solids: 2.0% pH: 5.9 Units  
Floc. Dosage: 0.484 lbs/ST

TABLE VIII  
FILTER PRESS SIZING SUMMARY

Hazen Research Inc.  
Arsenic Removal Project

Thickened Ferric Arsenate Precipitate

Recessed Plate Filter Press Design Criteria:

Material:	Thickened Ferric Arsenate Precipitate
Filter Feed Solids:	4.8%
Feed Temperature:	20°C
Feed Pressure:	80.0 psig
Filter Press Plate Type:	Recessed Plate
Plate Size:	48" or 60"
Plate Recess:	1.0"
Cake Thickness:	2.0"
Cake Moisture:	69%
Wet Bulk Density:	75.1 lbs/ft <sup>3</sup> (@ 69% moisture)
Sizing Basis <sub>(1)</sub> :	107.4 ft <sup>3</sup> /ST (dry solids)

Note:

- (1) Filter press sizing is limited by cake volume. Sizing basis in ft<sup>3</sup> of filter press volume per ST of dry solids. Sizing basis includes a 1.25 scale-up factor.



POCOCK INDUSTRIAL, INC.  
Pressure Filtration Test Data Sheet

Company: Hazen Research Inc.  
Arsenic Removal Project

Material to be Filtered: FERRIC Arsenate Precipitate

See % Solids, Consisting of Ferric Arsenate Precipitate (Thickened)  
Col. Q % Liquid, Consisting of Filtrate

Slurry Temp: 20 °C  
Slurry pH: 5.9 Units  
Liquid SG: 1.00  
Solids SG: 3.18

Table No.: VII  
Test Date: July 28, 1993  
By: ST  
Location: HRI Lab

Filter Area: 0.0191 sq ft  
Filter Cloth: 10 - 15 cfm Polypropylene Felt  
Slurry Feed Press.: 80 psig  
Floc Type: None

Test No.	Filtration Pressure (psig)			Filtration Time (minutes)								Cake Weight (grams)												Notes	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W		X
1	80.0	---	80.0	7.56	---	---	0.50	Y-T	---	114.5	---	0.34	16.91	6.29	66.7		4.71	0.73	0.69						133.41
2	80.0	---	80.0	20.91	---	---	0.50	Y-T	---	180.0	---	0.63	35.04	10.49	70.1		4.88	1.21	0.41						215.04
3	80.0	---	80.0	13.40	---	---	0.50	Y-T	---	144.5	---	0.47	26.51	8.27	66.8		4.84	0.95	0.52						171.01
4	80.0	---	80.0	42.34	---	---	0.50	Y-T	---	256.0	---	0.91	51.24	15.00	70.7		4.88	1.73	0.29						307.24
5	80.0	---	80.0	66.82	---	---	2.00	Y-T	---	301.0	---	1.06	67.68	17.69	69.4		4.93	2.04	0.96						356.68

Notes:

A: Form Pressure  
B: Wash Pressure  
C: Dry (Air Blow) Pressure  
D: Form time  
E: Pre-wash dry time  
F: Wash time  
G: Dry time  
H: Presence of cake cracks

I: Discharge air flow (cf/Dry Time)  
J: Filtrate volume (mls)  
K: Wash volume (mls)  
L: Cake thickness (in.)  
M: Wet cake weight (gms)  
N: Dry cake weight (gms)  
O: Cake moisture (%)  
P: acfm/sq ft @ pressure

Q:  $\frac{\text{Dry Wt} \times 100}{\text{Wet Wt} + \text{Filtrate Wt}}$   
R: Cake weight (W) as dry lbs per sq ft  
S: (Dry time)/(W)

T: (Wash volume in gal/leaf area) \* (W)  
U: Corrected repulp solution assay  
V: Corrected mother liquor assay  
W:  $\frac{\text{Corrected repulp solution assay}}{\text{Corrected mother liquor assay}}$

X:  $\frac{\text{Wash volume in mls}}{\text{Wet Wt} - \text{Dry Wt} / (\text{Solution SG})}$   
Y: Pulp weight (gms)

008475

**POCOCK INDUSTRIAL, INC.**  
Filter Press Test Data Sheet

008476

Company: Hazen Research Inc.  
Arsenic Removal Project

Table No.: V1a  
Test Date: July 27, 1993  
By: ST  
Location: HRI Lab

Material to be Filtered: FERRIC Arsenate Precipitate

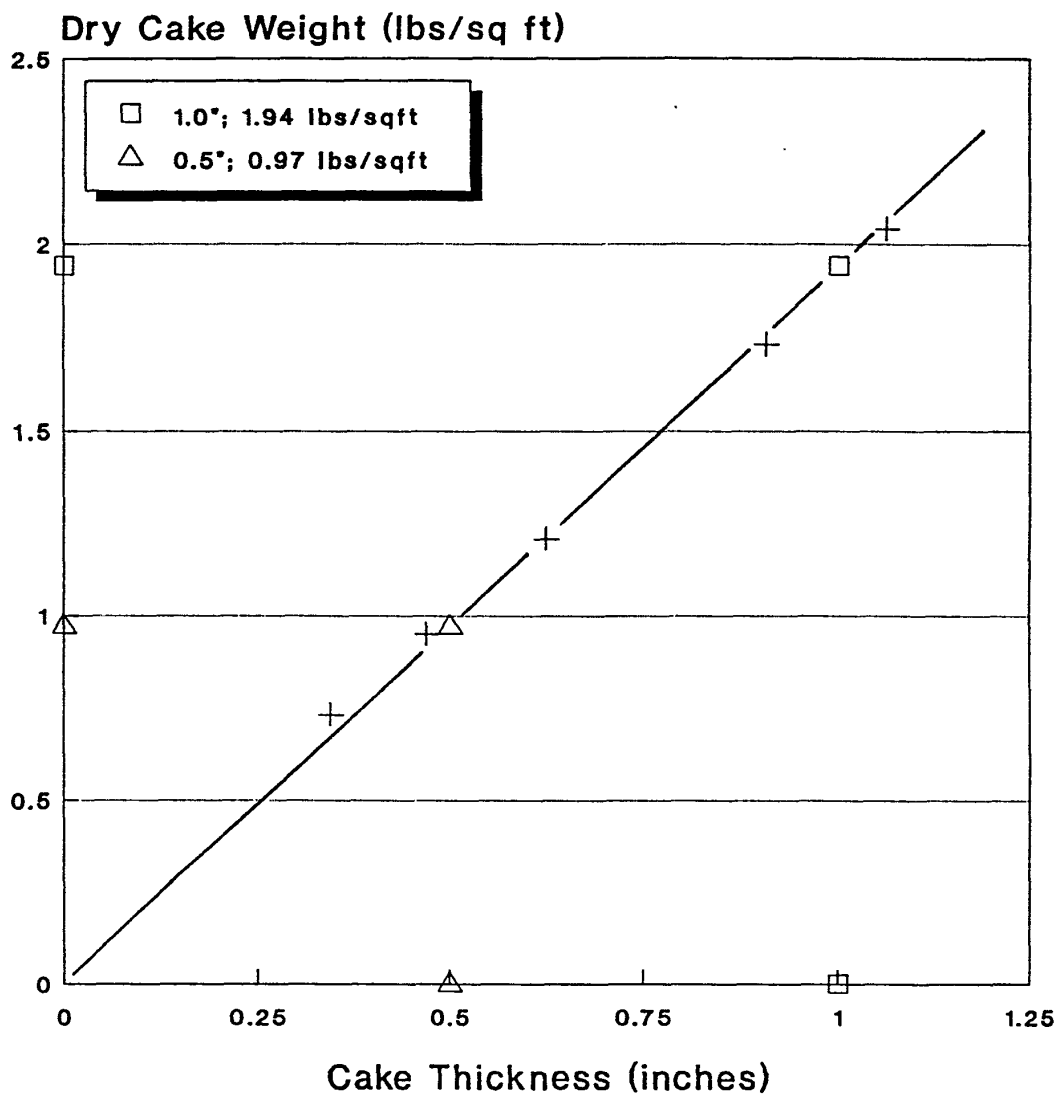
4.8 % Solids, Consisting of Ferric Arsenate Precipitate (Thickened)  
95.2 % Liquid, Consisting of Filtrate

Slurry Temp: 20 °C  
Slurry pH: 5.9 Units  
Liquid SG: 1.00  
Solids SG: 3.18

Filter Area: 0.0191 ft<sup>2</sup>  
Filter Cloth: 10 - 15 cfm Felt  
Slurry Feed Press.: 80 psig

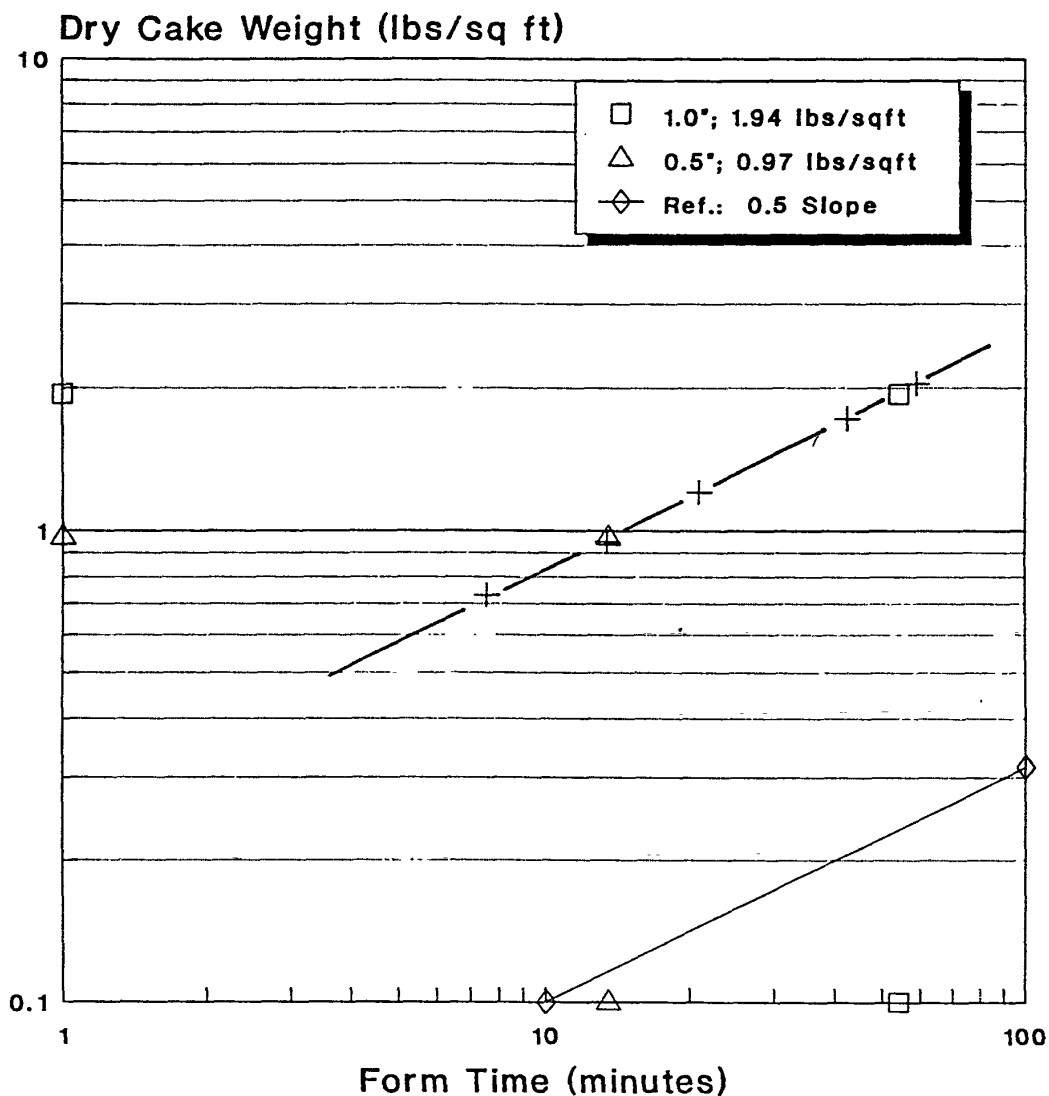
Test No.	Time (min.)	Filtrate Volume (mls)	Instant. Flow Rate (gpm/ft <sup>2</sup> )	Total Time (min.)	Total Flow (mls)	Average Flow Rate (gpm/ft <sup>2</sup> )
1	5.00	80.0	0.22	5.00	80	0.22
2	5.00	38.0	0.11	10.00	118	0.16
3	5.00	27.0	0.07	15.00	145	0.13
4	10.00	43.0	0.06	25.00	188	0.10
5	10.00	33.0	0.05	35.00	221	0.09
6	10.00	34.0	0.05	45.00	255	0.08
7	13.82	46.0	0.05	58.82	301	0.07

**FIG 7a: CAKE WEIGHT vs. CAKE THICKNESS**  
**Hazen Research Inc.**  
**Pressure Filtration**



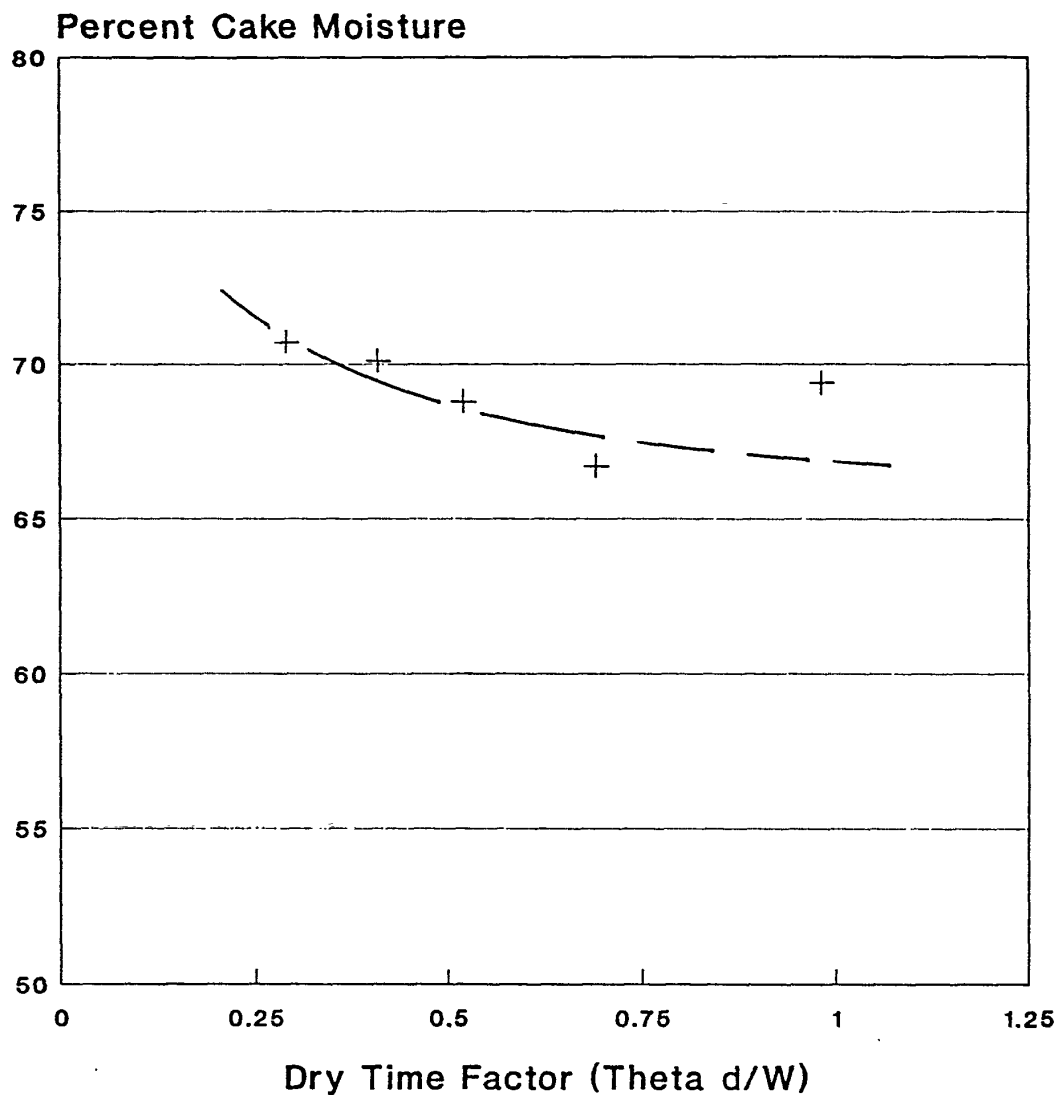
Mat'l: Ferric Arsenate Precipitate  
Feed Solids: 4.8% Nom.  
See Table VII for Parameters.

FIG 7b: CAKE WEIGHT vs. FORM TIME  
Hazen Research Inc.  
Pressure Filtration



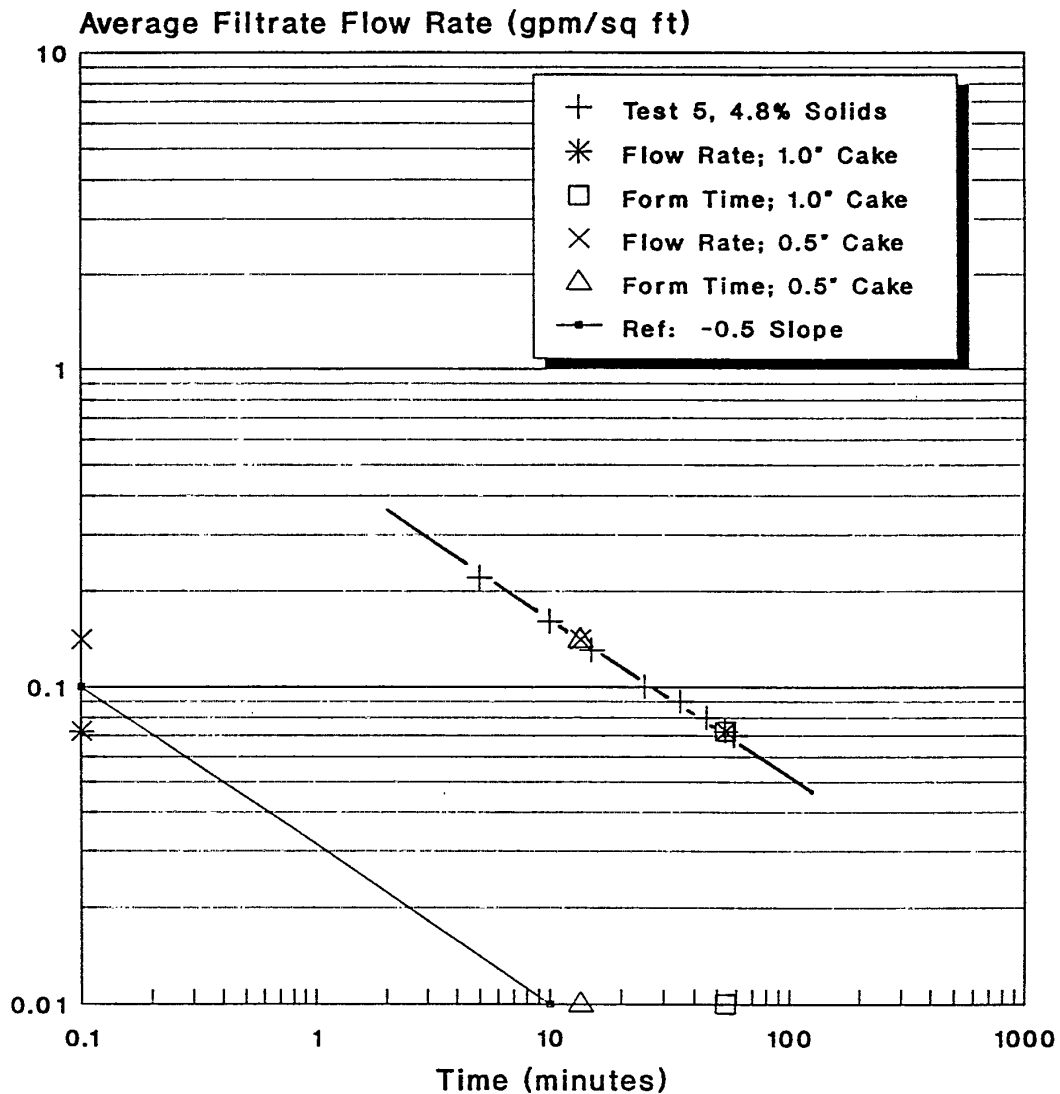
Mat'l: Ferric Arsenate Precipitate  
Feed Solids: 4.8% Nom.  
See Table VII for Parameters.

**FIG 7c: CAKE MOIST. vs. DRY TIME FACTOR**  
**Hazen Research Inc.**  
**Pressure Filtration**



Mat'l: Ferric Arsenate Precipitate  
Feed Solids: 4.8% Nom.  
See Table VII for Parameters.

FIG 7d: FILTRATE FLOW RATE vs. TIME  
Hazen Research Inc.  
Pressure Filtration



Mat'l: Ferric Arsenate Precipitate  
Feed Solids: 4.8%  
See Table VIIa for Parameters.

**TABLE VIII****FILTER PRESS SIZING SUMMARY**

Hazen Research Inc.  
Arsenic Removal Project

**Thickened Ferrous Arsenate Precipitate****Recessed Plate Filter Press Design Criteria:**

Material:	Thickened Ferrous Arsenate Precipitate
Filter Feed Solids:	3.8%
Feed Temperature:	20°C
Feed Pressure:	80.0 psig
Filter Press Plate Type:	Recessed Plate
Plate Size:	48" or 60"
Plate Recess:	1.0"
Cake Thickness:	2.0"
Cake Moisture:	71%
Wet Bulk Density:	80.3 lbs/ft <sup>3</sup> (@ 71% moisture)
Sizing Basis <sub>(1)</sub> :	107.4 ft <sup>3</sup> /ST (dry solids)

**Note:**

- (1) Filter press sizing is limited by cake volume. Sizing basis in ft<sup>3</sup> of filter press volume per ST of dry solids. Sizing basis includes a 1.25 scale-up factor.

POCOCK INDUSTRIAL, INC.  
Pressure Filtration Test Data Sheet

Company: Hazen Research Inc.  
Asbestos Removal Project

Material to be Filtered: FERROUS Arsenate Precipitate

See % Solids, Consisting of Ferrous Arsenate Precipitate (Thickened)  
Col. Q. % Liquid, Consisting of Filtrate

Slurry Temp: 20 °C  
Slurry pH: 5.8 Units  
Liquid SG: 1.00  
Solids SG: 3.18

Table No.: VN  
Test Date: July 28, 1993  
By: ST  
Location: HRI Lab  
Filter Area: 0.0191 sq ft  
Filter Cloth: 10 - 15 cfm Polypropylene Felt  
Slurry Feed Press.: 80 psig  
Floc Type: None

Test No.	Filtration Pressure (psig)			Filtration Time (minutes)								Cake Weight (grams)												Notes			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W		X	Y	
1	80.0	---	80.0	7.31	---	---	0.50	Y-S	---	118.5	---	0.25	14.92	4.32	69.7	3.39	0.82	0.96	---	---	---	---	---	---	---	133.42	
2	80.0	---	80.0	18.06	---	---	0.50	Y-S	---	178.5	---	0.47	23.96	7.48	71.2	3.86	0.86	0.56	---	---	---	---	---	---	---	204.46	
3	80.0	---	80.0	32.08	---	---	0.50	Y-S	---	235.5	---	0.59	33.38	9.87	70.4	3.67	1.14	0.44	---	---	---	---	---	---	---	206.88	
4	80.0	---	80.0	69.35	---	---	2.00	Y-S	---	363.5	---	0.94	53.79	19.67	68.0	3.73	1.92	1.04	---	---	---	---	---	---	---	447.29	

Notes:

- A: Form Pressure  
B: Wash Pressure  
C: Dry (Air Blow) Pressure  
D: Form time  
E: Pre-wash dry time  
F: Wash time  
G: Dry time  
H: Presence of cake cracks  
I: Discharge air flow (cf/Dry Time)  
J: Filtrate volume (ml)  
K: Wash volume (ml)  
L: Cake thickness (in.)  
M: Wet cake weight (gms)  
N: Dry cake weight (gms)  
O: Cake moisture (%)  
P: act/mq ft @ pressure  
Q:  $\frac{\text{Dry Wt} \times 100}{\text{Wet Wt} + \text{Filtrate Wt}}$   
R: Cake weight (W) as dry basis per sq ft  
S: Dry time/(W)  
T: (Wash volume in gal/leaf area) (W)  
U: Corrected input solution assay  
V: Corrected mother liquor assay  
W: Corrected input solution assay  
X:  $\frac{\text{Wash volume in ml}}{\text{Wet Wt} - \text{Dry Wt} / \text{Solution SG}}$   
Y: Pulp weight (gms)

008482



**POCOCK INDUSTRIAL, INC.**  
Filter Press Test Data Sheet

Company: Hazen Research Inc.  
Arsenic Removal Project

Table No.:  
Test Date: July 27, 1993  
By: ST  
Location: HRI Lab

Material to be Filtered: FERROUS Arsenate Precipitate

3.8 % Solids, Consisting of Ferrous Arsenate Precipitate (Thickened)  
96.2 % Liquid, Consisting of Filtrate

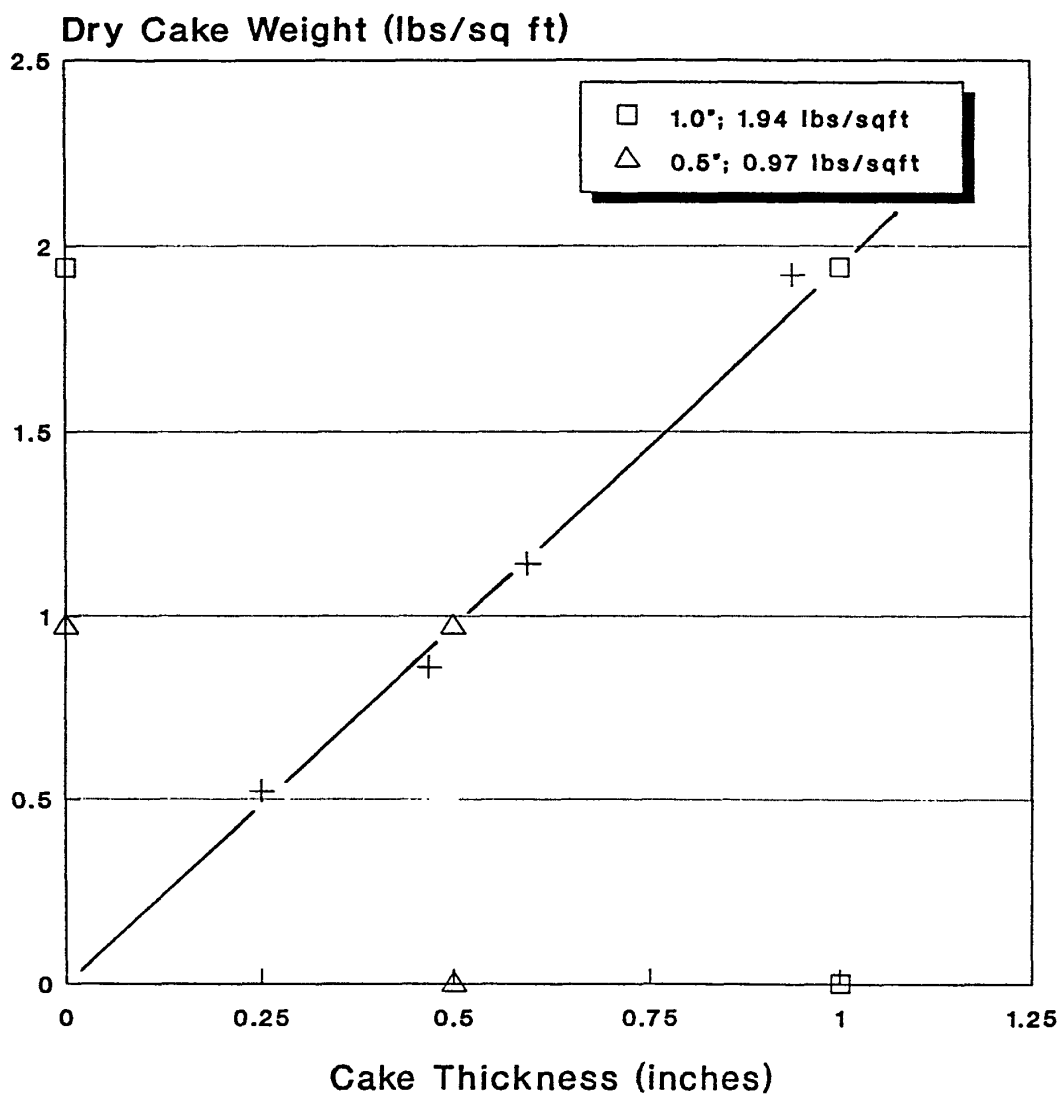
Slurry Temp: 20 °C  
Slurry pH: 5.9 Units  
Liquid SG: 1.00  
Solids SG: 3.18

Filter Area: 0.0191 ft<sup>2</sup>  
Filter Cloth: 10 - 15 cfm Felt  
Slurry Feed Press.: 80 psig

Test No.	Time (min.)	Filtrate Volume (mls)	Instant Flow Rate (gpm/ft <sup>2</sup> )	Total Time (min.)	Total Flow (mls)	Average Flow Rate (gpm/ft <sup>2</sup> )
1	5.00	85.5	0.24	5.00	86	0.24
2	5.00	38.5	0.11	10.00	124	0.17
3	5.00	28.5	0.08	15.00	153	0.14
4	10.00	48.5	0.07	25.00	201	0.11
5	10.00	36.5	0.05	35.00	238	0.09
6	10.00	34.0	0.05	45.00	272	0.08
7	44.35	122.0	0.04	89.35	394	0.06

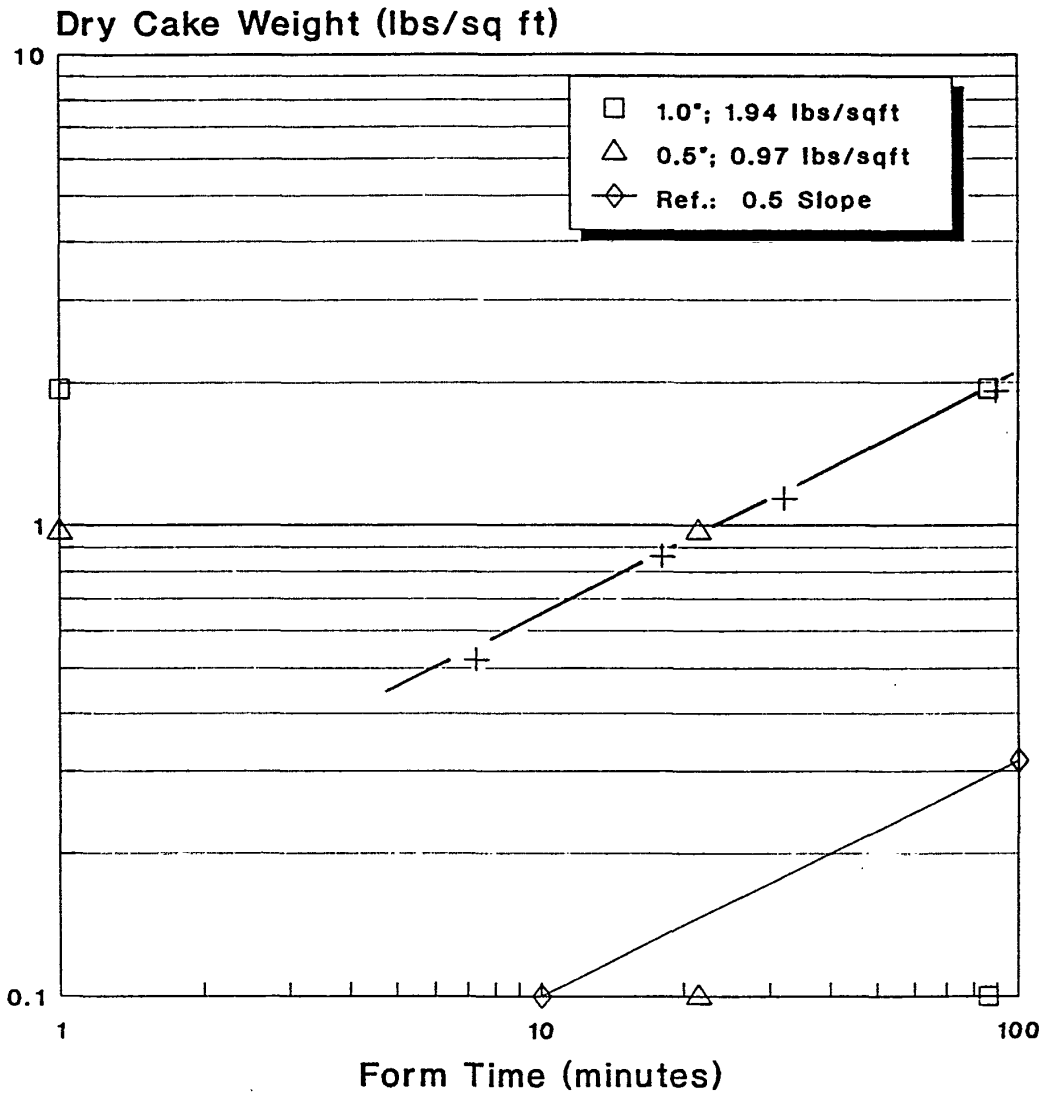
008483

**FIG 8a: CAKE WEIGHT vs. CAKE THICKNESS**  
Hazen Research Inc.  
Pressure Filtration



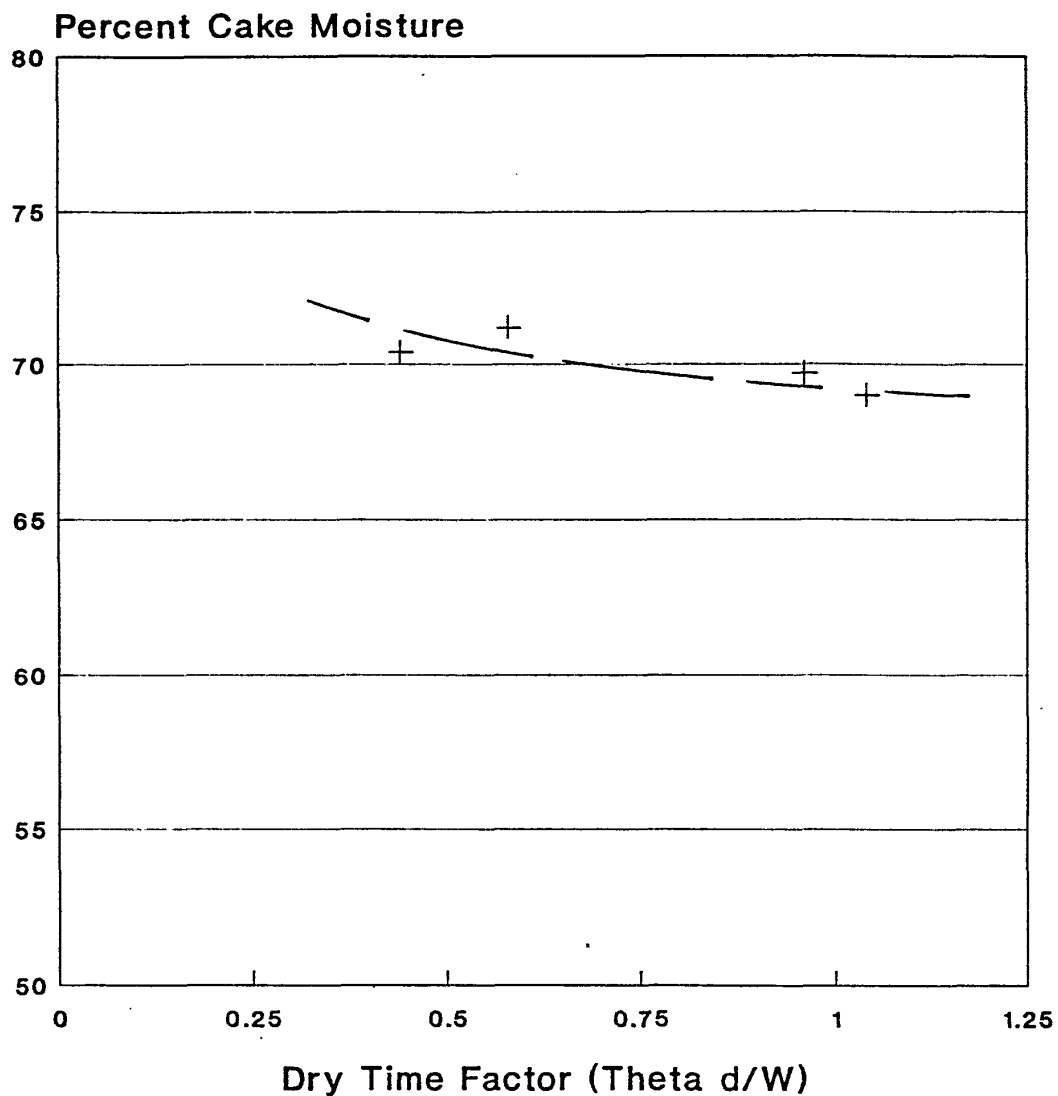
Mat'l: Ferrous Arsenate Precipitate  
Feed Solids: 3.8% Nom.  
See Table VIII for Parameters.

FIG 8b: CAKE WEIGHT vs. FORM TIME  
Hazen Research Inc.  
Pressure Filtration



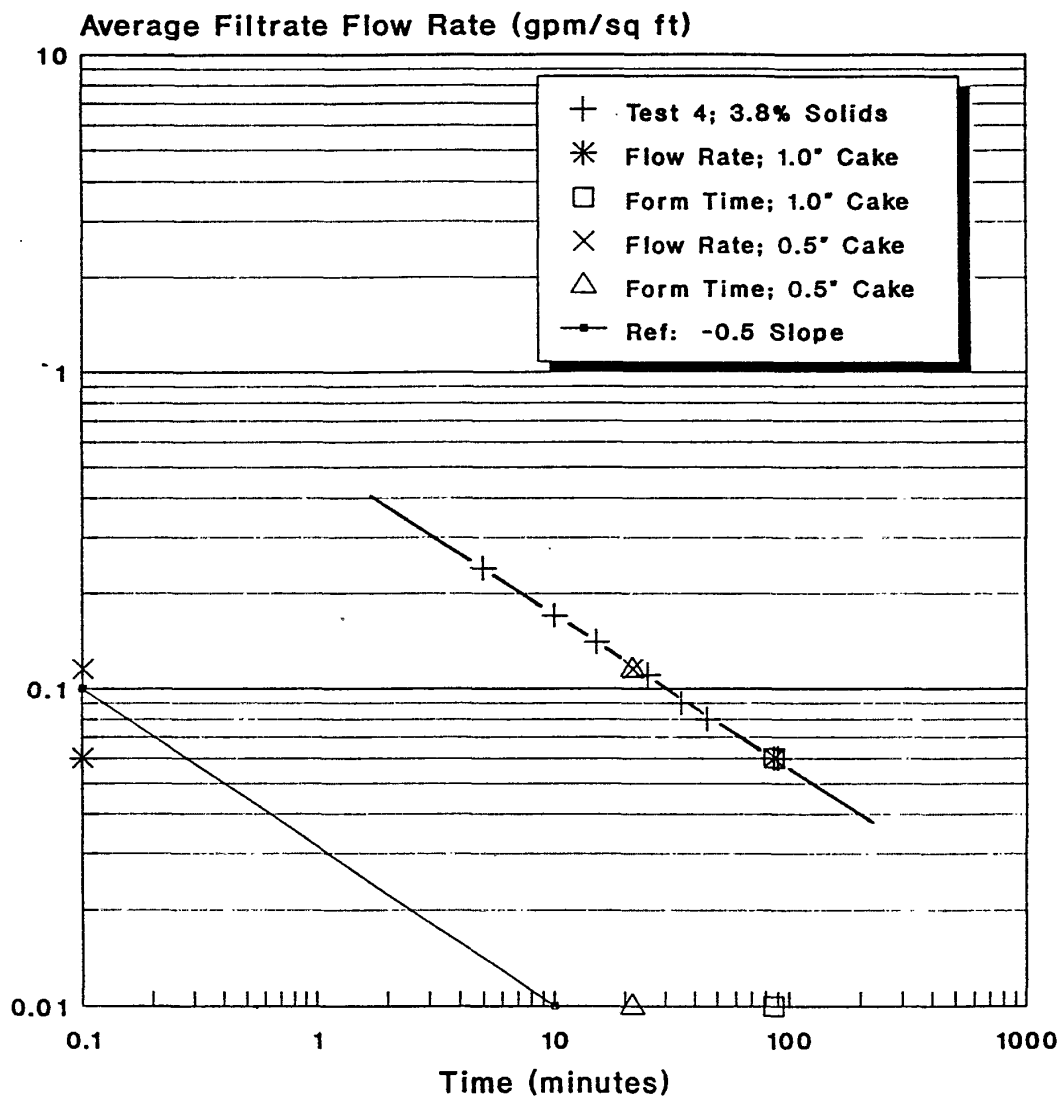
Mat'l: Ferrous Arsenate Precipitate  
Feed Solids: 3.8% Nom.  
See Table VIII for Parameters.

FIG 8c: CAKE MOIST. vs. DRY TIME FACTOR  
Hazen Research Inc.  
Pressure Filtration



Mat'l: Ferrous Arsenate Precipitate  
Feed Solids: 3.8% Nom.  
See Table VIII for Parameters.

FIG 8d: FILTRATE FLOW RATE vs. TIME  
Hazen Research Inc.  
Pressure Filtration



Mat'l: Ferrous Arsenate Precipitate  
Feed Solids: 3.8%  
See Table VIIIa for Parameters.

**TABLE IXi****VACUUM FILTER SIZING SUMMARY**

Hazen Research Inc.  
Arsenic Removal Project

**Thickened Ferric Arsenate Precipitate****Vacuum Drum Filter Operating Parameters:**

Material:	Thickened Ferric Arsenate Precipitate
Filter Feed Solids:	4.8%
Feed Temperature:	20°C
Vacuum Level:	18 "Hg
Filter Aid/Flocculant:	Residual from Thickening
Cake Thickness:	3/8 inch
Cake Moisture:	71.0%
Cake Wash:	Not Required
Cake Weight:	0.68 dry lbs/ft <sup>2</sup> (@ 3/8 in. thickness)
Wet Bulk Density:	75.0 lbs/ft <sup>3</sup> (@ 71% moisture)

**Vacuum Drum Filter (scraper-type) Sizing:**

Form Time:	14.2 min.
Dry Time (calculated):	21.5 min.
Cycle Time (Form Time/0.33):	43.0 min.
Production Rate <sub>(1,2)</sub> :	0.76 dry lbs/ft <sup>2</sup> •hr

**Notes:**

- (1) Production Rate includes a 0.8 scale-up factor.
- (2) Cycle Time and thus, Production Rate are form time limited.

POCOCK INDUSTRIAL, INC.  
Vacuum Filtration Test Data Sheet

Company: Hazen Research Inc.  
Arsenic Removal Project

Material to be Filtered: FERRIC Arsenate Precipitate

See % Solids, Consisting of Ferric Arsenate Precipitate (Thickened)  
Col. Q % Liquid, Consisting of Filtrate

Slurry Temp: 20 Deg C  
Slurry pH: 5.9  
Liquid SG: 1.00  
Solids SG: 3.18

Table No.: 0X  
Test Date: 07/22/83  
By: ST  
Location: HRI Lab

Filter Area: 0.1 sq ft  
Filter Cloth: 0.5-1.0 cfm/sqft Dacron Cloth  
Floc Type: (Residual from Thickening)

Repulp Volume: 0 ml

Test No.	Filtration Vacuum (In. Hg)			Filtration Time (minutes)								Cake Weight (grams)														Notes
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	
1	18.0	----	18.0	0.98	----	----	2.00	N	----	136.0	----	0.09	25.54	7.48	70.7		4.83	0.16	12.13							181.54
2	18.0	----	18.0	3.85	----	----	2.00	Y-S	----	272.5	----	0.19	54.30	16.08	70.4		4.91	0.35	5.85							326.80
3	18.0	----	18.0	7.52	----	----	3.00	Y-S	----	368.5	----	0.25	73.73	22.24	68.8		5.03	0.49	6.12							442.23
4	18.0	----	18.0	21.02	----	----	4.50	Y-T	----	602.5	----	0.47	126.33	37.10	70.8		5.09	0.82	5.50							728.63
5	18.0	----	18.0	1.82	----	----	5.00	Y-S	----	177.0	----	0.13	33.81	10.38	68.3		4.92	0.23	21.85							210.81

Notes:

A: Form Vacuum  
B: Wash Vacuum  
C: Dry Vacuum  
D: Form time  
E: Pre-wash dry time  
F: Wash time  
G: Dry time  
H: Presence of cake cracks

I: Discharge air flow (cf/Dry Time)  
J: Filtrate volume (mls)  
K: Wash volume (mls)  
L: Cake thickness (in.)  
M: Wet cake weight (gms)  
N: Dry cake weight (gms)  
O: Cake moisture (%)  
P: acfm/sq ft @ pressure

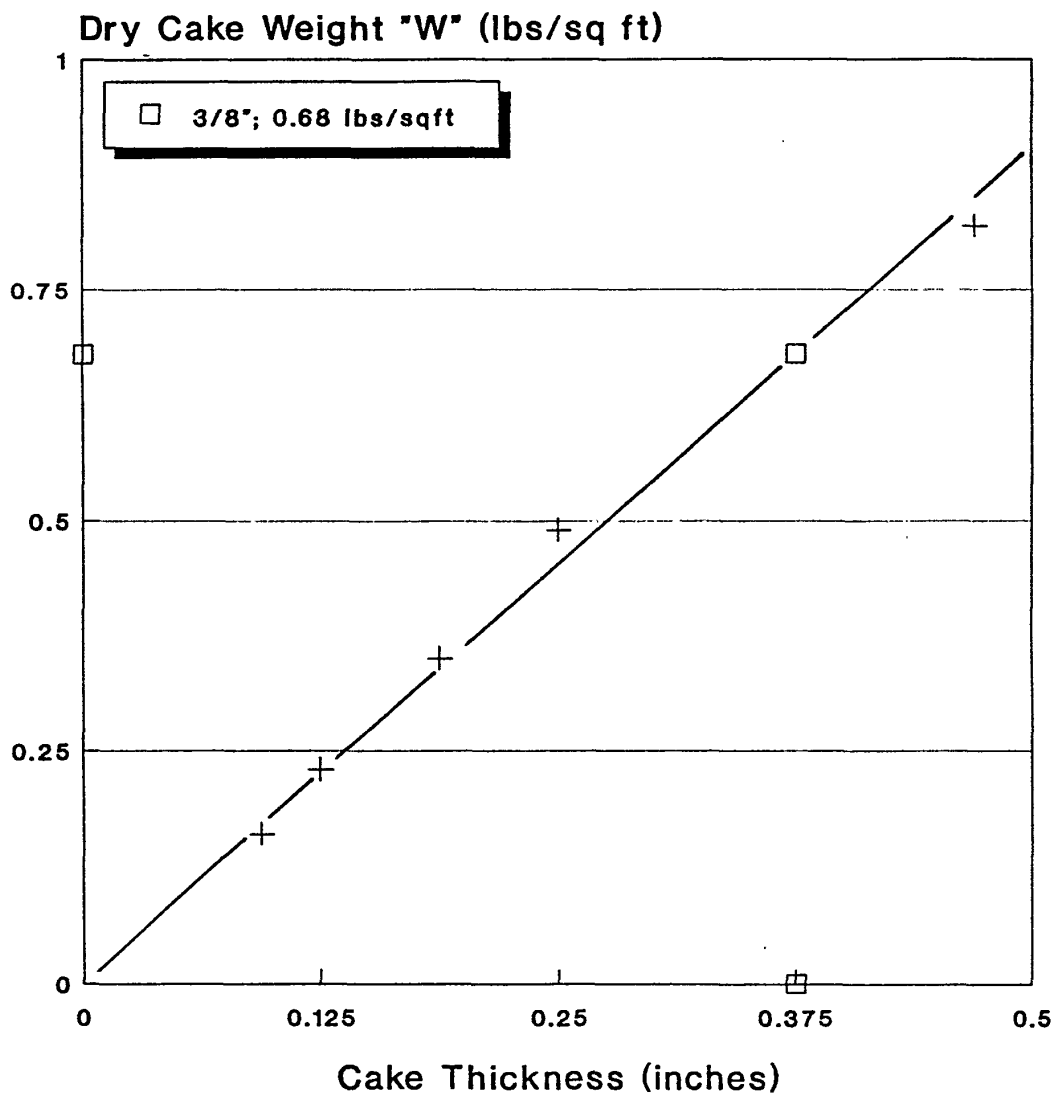
Q:  $\frac{(\text{Dry Wt} \times 100)}{(\text{Wet Wt} + \text{Filtrate Wt})}$   
R: Cake weight (W) as dry lbs per sq ft  
S: (Dry time)/(W)

T: (Wash volume in gal/leaf area)\*(W)  
U: Corrected repulp solution assay  
V: Corrected mother liquor assay  
W:  $\frac{\text{Corrected repulp solution assay}}{\text{Corrected mother liquor assay}}$

X:  $\frac{\text{Wash volume in mls}}{(\text{Wet Wt} - \text{Dry Wt}) / (\text{Solution SG})}$   
Y: Pulp weight (gms)

008489

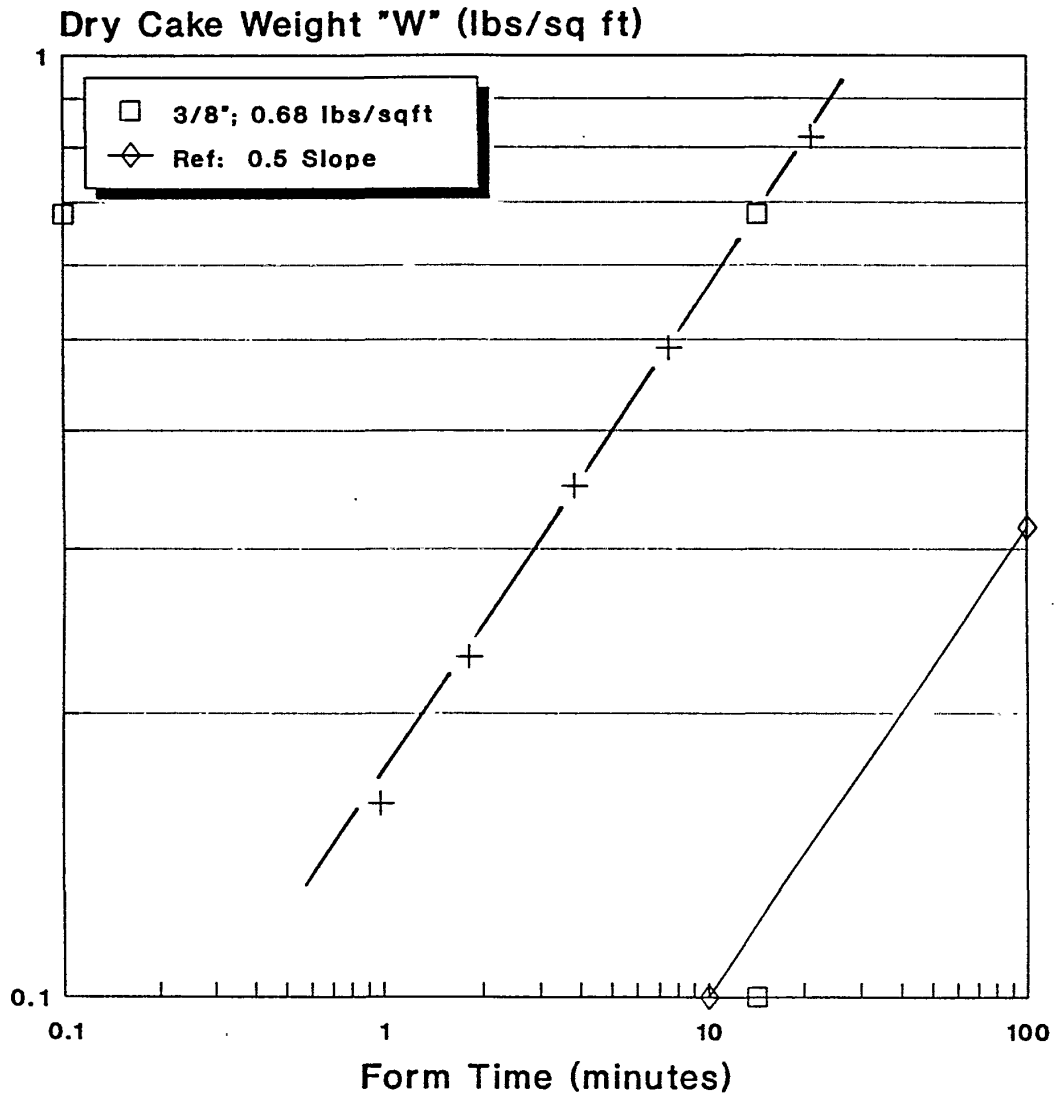
**FIG 9a: CAKE WEIGHT vs. CAKE THICKNESS**  
Hazen Research Inc.  
Vacuum Filtration



Mat'l: Ferric Arsenate Precipitate  
Feed Solids: 5.9% Nom.  
See Table IX for Parameters

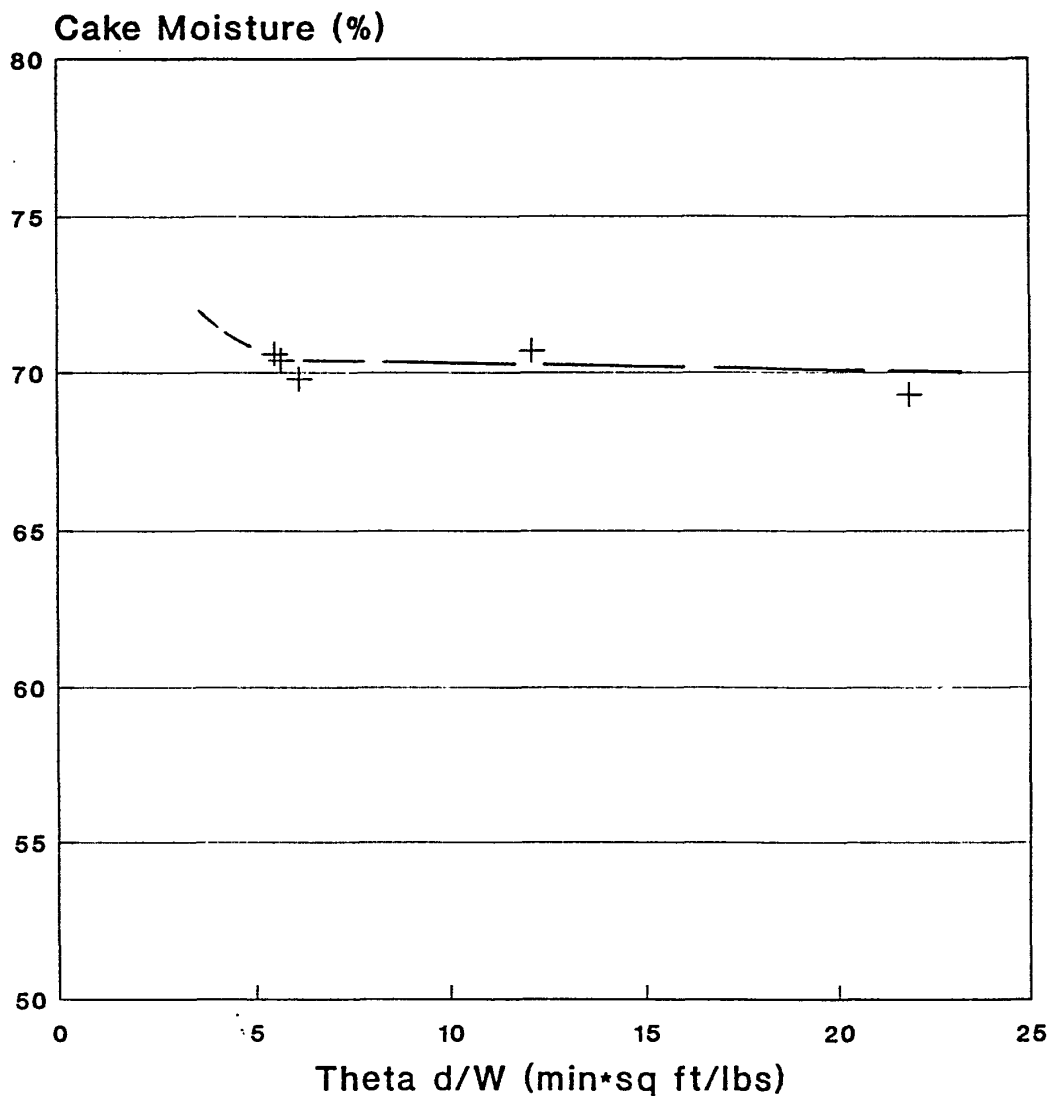


**FIG 9b: DRY CAKE WEIGHT vs. FORM TIME**  
Hazen Research Inc.  
Vacuum Filtration



Mat'l: Ferric Arsenate Precipitate  
Feed Solids: 5.9% N0m.  
See Table IX for Parameters

FIG 9c: PERCENT MOISTURE vs THETA d/W  
Hazen Research Inc.  
Vacuum Filtration



Mat'l: Ferric Arsenate Precipitate  
Feed Solids: 5.9% Nom.  
See Table IX for Parameters

TABLE XiVACUUM FILTER SIZING SUMMARY

Hazen Research Inc.  
Arsenic Removal Project

Thickened Ferrous Arsenate PrecipitateVacuum Drum Filter Operating Parameters:

Material:	Thickened Ferrous Arsenate Precipitate
Filter Feed Solids:	3.8%
Feed Temperature:	20°C
Vacuum Level:	18 "Hg
Filter Aid/Flocculant:	Residual from Thickening
Cake Thickness:	3/8 inch
Cake Moisture:	74.0%
Cake Wash:	Not Required
Cake Weight:	0.62 dry lbs/ft <sup>2</sup> (@ 3/8 in. thickness)
Wet Bulk Density:	76.3 lbs/ft <sup>3</sup> (@ 74% moisture)

Vacuum Drum Filter (scraper-type) Sizing:

Form Time:	23.0 min.
Dry Time (calculated):	34.8 min.
Cycle Time (Form Time/0.33):	69.7 min.
Production Rate <sub>(1,2)</sub> :	0.43 dry lbs/ft <sup>2</sup> •hr

Notes:

- (1) Production Rate includes a 0.8 scale-up factor.
- (2) Cycle Time and thus, Production Rate are form time limited.

POCOCK INDUSTRIAL, INC.  
Vacuum Filtration Test Data Sheet

Company: Hazen Research Inc.  
Arsenic Removal Project

Material to be Filtered: FERROUS Arsenate Precipitate

See % Solids, Consisting of Ferrous Arsenate Precipitate (Thickened)  
Col. Q % Liquid, Consisting of Filtrate

Slurry Temp: 20 Deg C  
Slurry pH: 5.9  
Liquid SG: 1.00  
Solids SG: 3.16

Table No.: X  
Test Date: 07/27/83  
By: ST  
Location: HRI Lab

Filter Area: 0.1 sq ft  
Filter Cloth: 0.5-1.0 cm/sqft Dacron Cloth  
Floc Type: (Residual from Thickening)

Repulp Volume: 0 ml

Test No.	Filtration Vacuum (in. Hg)			Filtration Time (minutes)								Cake Weight (grams)												Notes		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W		X	Y
1	18.0	---	18.0	1.72	---	---	3.00	N	---	167.0	---	0.09	27.50	7.18	73.9		3.69	0.18	18.95							194.00
2	18.0	---	18.0	20.57	---	---	3.00	N	---	568.0	---	0.38	103.21	26.56	74.3		3.84	0.59	5.12							891.21
3	18.0	---	18.0	32.18	---	---	6.00	Y-S	---	726.0	---	0.44	120.70	33.09	72.6		3.91	0.73	6.22							846.70

Notes:

A: Form Vacuum  
B: Wash Vacuum  
C: Dry Vacuum  
D: Form time  
E: Pre-wash dry time  
F: Wash time  
G: Dry time  
H: Presence of cake cracks

I: Discharge air flow (cf/Dry Time)  
J: Filtrate volume (mls)  
K: Wash volume (mls)  
L: Cake thickness (in.)  
M: Wet cake weight (gms)  
N: Dry cake weight (gms)  
O: Cake moisture (%)  
P: acfm/sq ft @ pressure

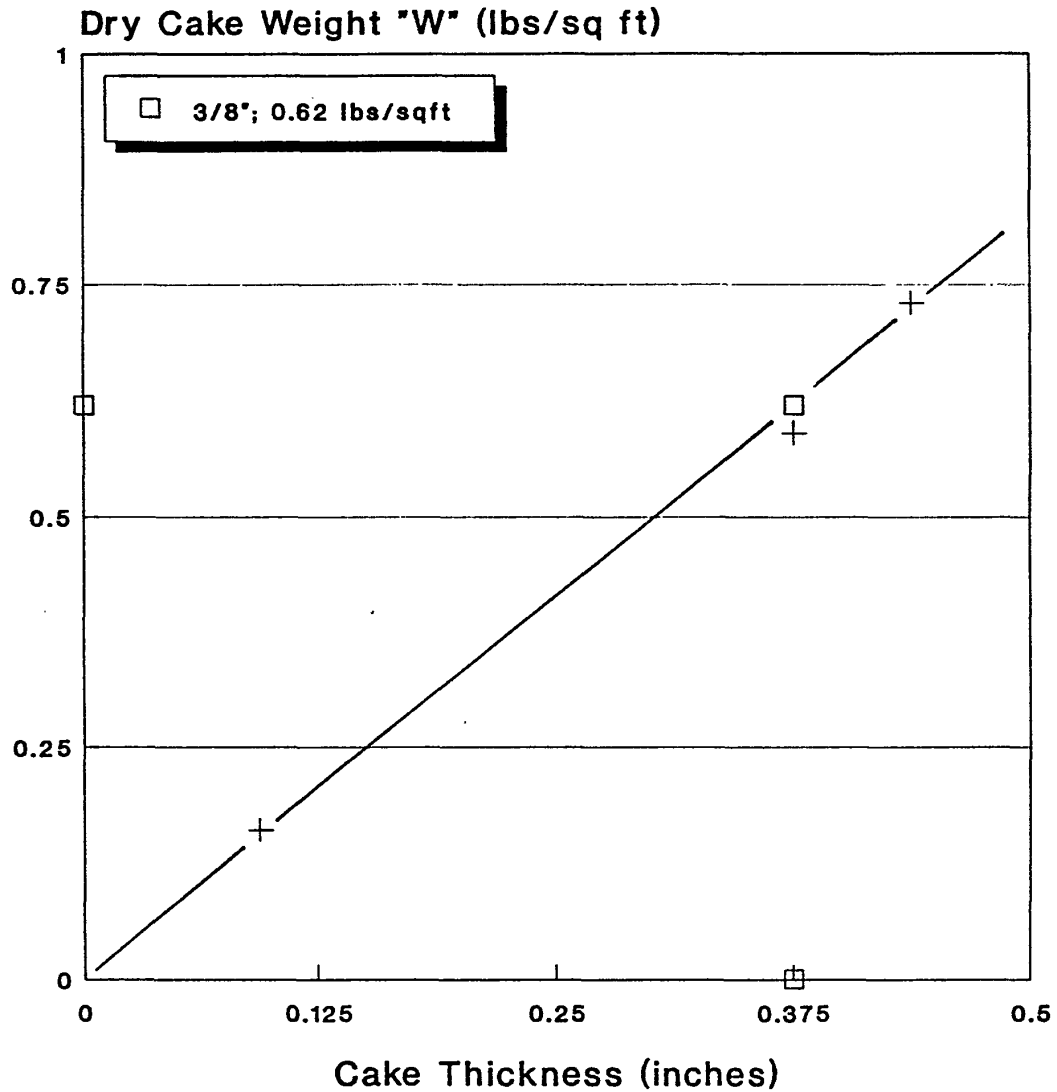
Q:  $\frac{\text{Dry Wt} \times 100}{\text{Wet Wt} + \text{Filtrate Wt}}$   
R: Cake weight (W) as dry lbs per sq ft  
S: (Dry time)/(W)

T: (Wash volume in gal/leaf area)\*(W)  
U: Corrected repulp solution assay  
V: Corrected mother liquor assay  
W:  $\frac{\text{Corrected repulp solution assay}}{\text{Corrected mother liquor assay}}$

X:  $\frac{\text{Wash volume in mls}}{\text{Wet Wt} - \text{Dry Wt} / \text{Solution SG}}$   
Y: Pulp weight (gms)

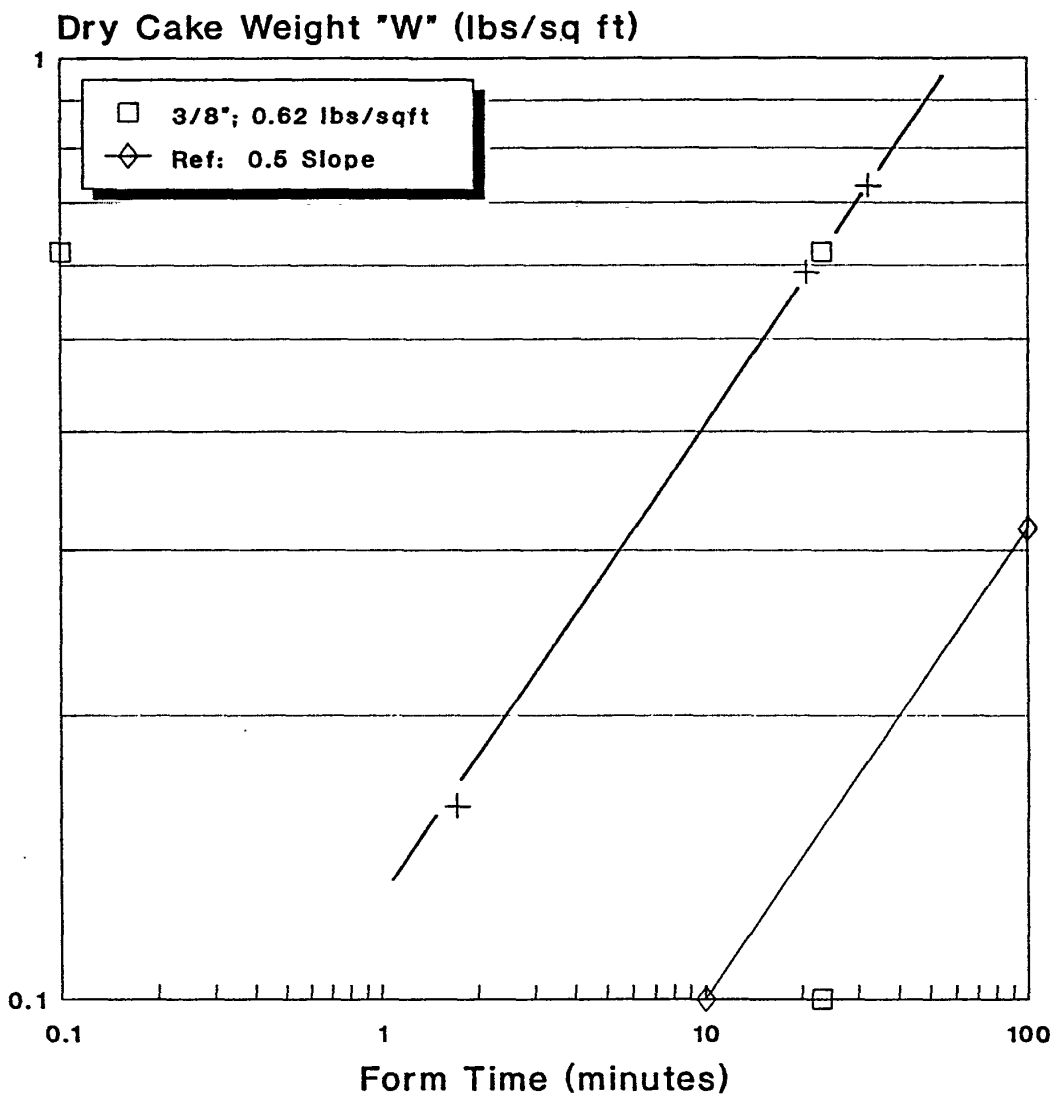
008494

**FIG 10a: CAKE WEIGHT vs. CAKE THICKNESS**  
Hazen Research Inc.  
Vacuum Filtration



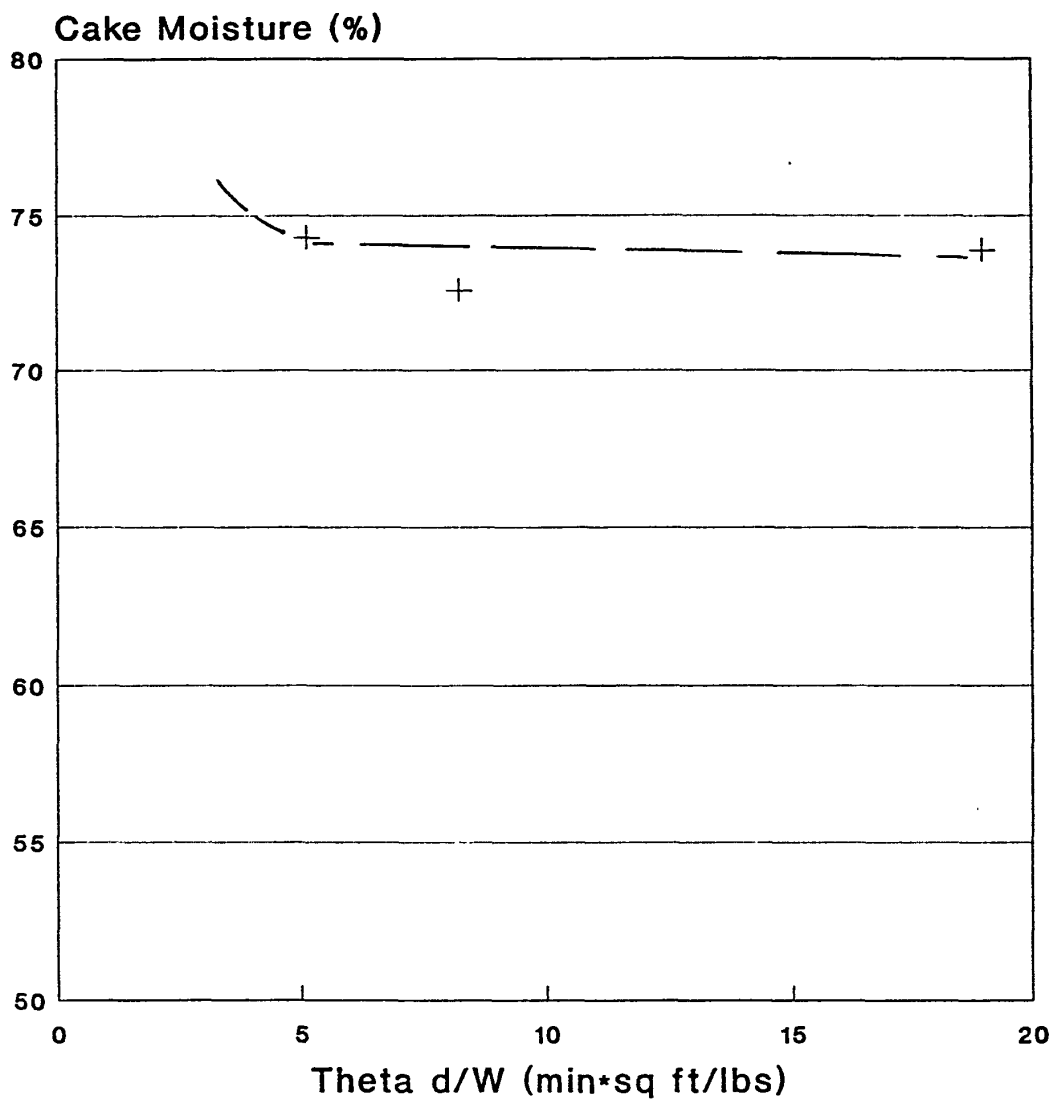
Mat'l: Ferrous Arsenate Precipitate  
Feed Solids: 3.8% Nom.  
See Table X for Parameters

FIG 10b: DRY CAKE WEIGHT vs. FORM TIME  
Hazen Research Inc.  
Vacuum Filtration



Mat'l: Ferrous Arsenate Precipitate  
Feed Solids: 3.8% Nom.  
See Table X for Parameters

**FIG 10c: PERCENT MOISTURE vs THETA d/W**  
**Hazen Research Inc.**  
**Vacuum Filtration**



Mat'l: Ferrous Arsenate Precipitate  
Feed Solids: 3.8% Nom.  
See Table X for Parameters

008498

**POCOCK INDUSTRIAL, INC**  
**Rheological Properties Data Sheet**

Company: Hazen Research Inc.  
 Arsenic Removal Project  
 Ferric Arsenate Precipitate (Filter Feed)

4.8 % Solids Consisting of Ferric Arsenate Precipitate  
 95.2 % Liquid Consisting of Treated Water

Floc Type: Allied Colloids Percol 351 (Nonionic Polyacrylamide)  
 Floc Dosage: 0.153 - 0.418 lbs/ST (Residual)  
 Floc Conc: 0.2 g/l  
 Pulp Sample: Filter Feed

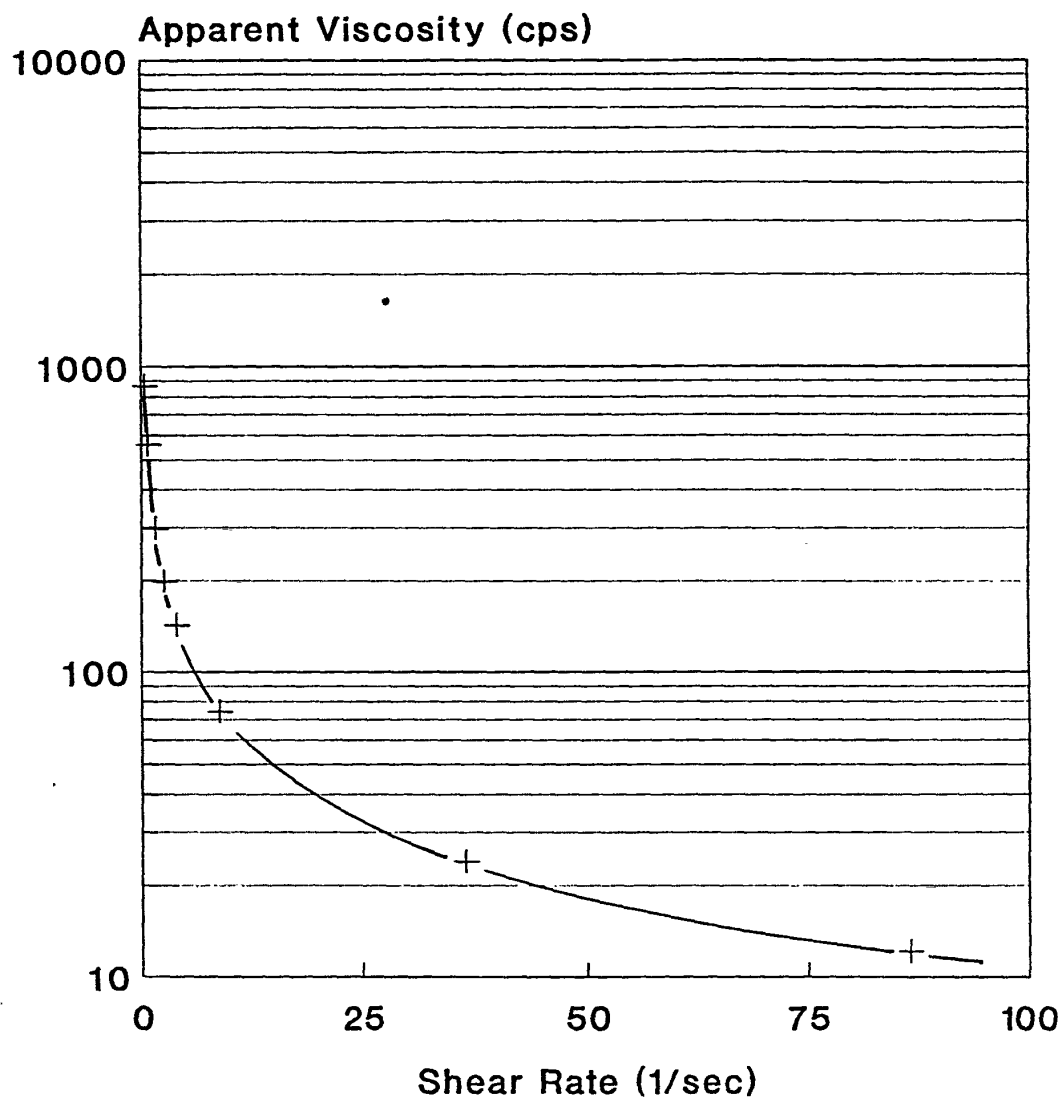
Table No.: XI  
 Test No.: 1  
 Test Date: 07/27/83  
 By: ST  
 Location: HRI Lab

pH: 5.9 Units  
 Temp: 20 Deg C

Spindle Type:		Cylindrical			
Spindle No.:		1			
Spindle Length:		7.4930 cm			
Spindle Radius:		0.9421 cm			
RPM	Reading	Shear Stress	Shear Rate	Apparent Viscosity	Constants and Sums
0.3	21.0	3.38	0.39	867.53	N = 8.00
0.6	23.5	3.79	0.68	561.24	H = -0.35
1.5	27.8	4.48	1.51	297.56	E = 36.35
3	31.0	4.99	2.51	198.63	n = 0.21
6	33.9	5.46	3.85	141.61	F = 7.61
12	40.2	6.47	8.71	74.31	I = 0.82
30	54.2	8.74	36.51	23.93	G = 0.75
60	64.9	10.46	86.49	12.10	k = 4.12



**FIG 11: RHEOLOGICAL PROPERTIES**  
**Apparent Viscosity vs. Shear Rate**  
Hazen Research Inc.



Mat'l: Ferric Arsenate Precipitate  
Solids Concentration: 4.8%  
Spindle #1

008500

**POCOCK INDUSTRIAL, INC**  
**Rheological Properties Data Sheet**

Company: Hazen Research Inc.  
 Arsenic Removal Project  
 Ferrous Arsenate Precipitate (Filter Feed)

3.8 % Solids Consisting of Ferrous Arsenate Precipitate  
 96.2 % Liquid Consisting of Treated Water

Floc Type: Allied Colloids Percol 351 (Nonionic Polyscrylamide)  
 Floc Dosage: 0.191 - 0.456 lbs/ST (Residual)  
 Floc Conc: 0.2 g/l  
 Pulp Sample: Filter Feed

Table No.: XII  
 Test No.: 1  
 Test Date: 07/27/93  
 By: ST  
 Location: HRI Lab

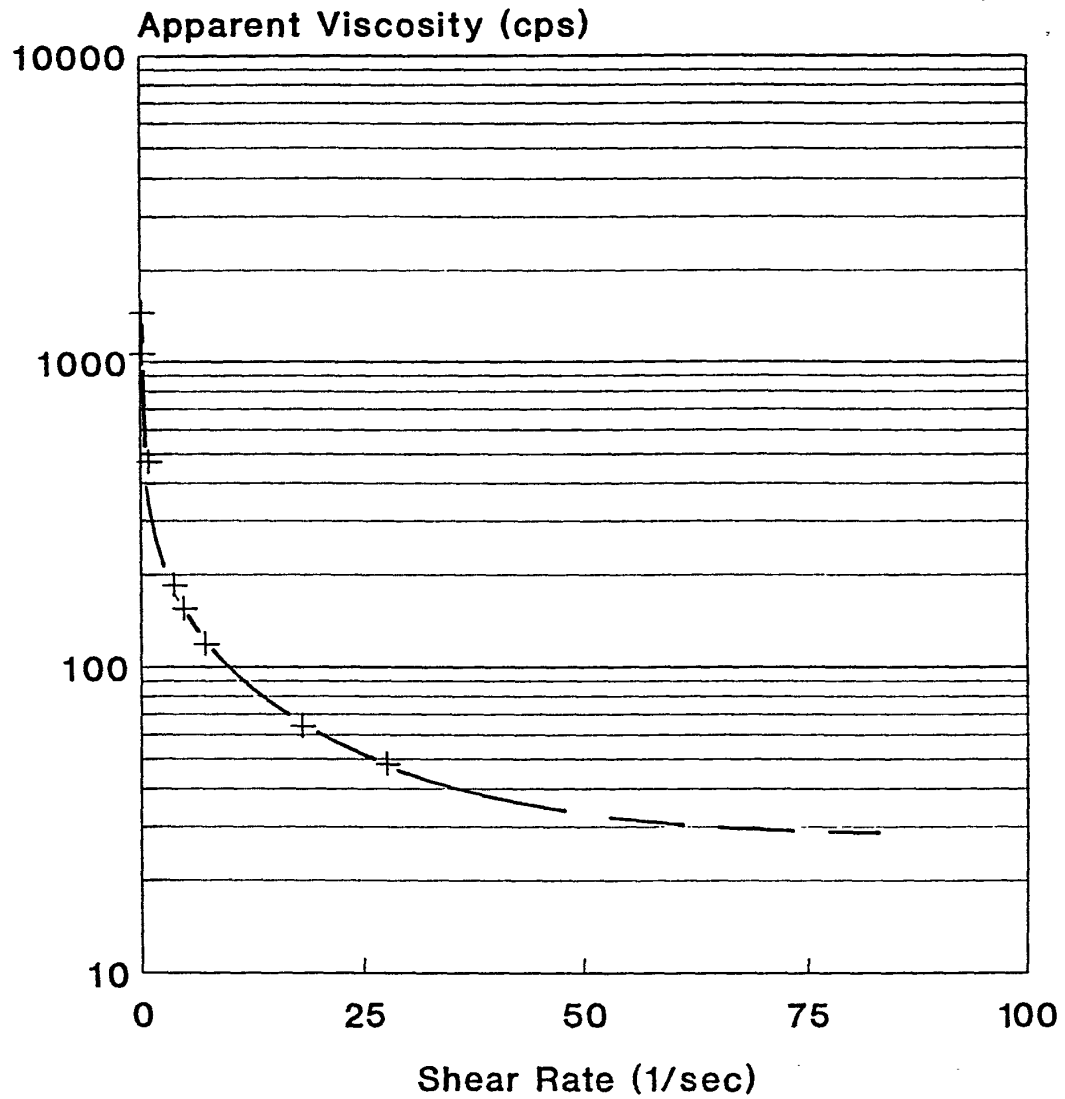
pH: 5.9 Units  
 Temp: 20 Deg C

Spindle Type:	Cylindrical
Spindle No.:	1
Spindle Length:	7.4930 cm
Spindle Radius:	0.9421 cm

RPM	Reading	Shear Stress	Shear Rate	Apparent Viscosity	Constants and Sums	
0.3	14.8	2.39	0.16	1446.54	N =	8.00
0.6	17.3	2.79	0.26	1061.90	H =	-0.35
1.5	26.1	4.21	0.89	470.31	E =	36.35
3	41.9	6.75	3.67	184.18	n =	0.34
6	45.8	7.38	4.78	154.42	F =	12.20
12	52.4	8.45	7.15	118.19	I =	0.90
30	71.5	11.52	18.00	63.99	G =	0.78
60	82.5	13.30	27.64	48.12	k =	4.37

**FIG 12: RHEOLOGICAL PROPERTIES**  
**Apparent Viscosity vs. Shear Rate**  
Hazen Research Inc.



Mat'l: Ferrous Arsenate Precipitate  
Solids Concentration: 3.8%  
Spindle #1

**APPENDIX B**

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA  
Target Compound List

Client Sample Number	: 46836	Client I.D.	: 8068
Sample Number	: X74795	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93	Effective Dilution	: 1.00
Date Received	: 08/07/93	Method	: 624
Date Extracted/Prepared	: 08/20/93	Matrix	: WATER
Date Analyzed	: 08/20/93	Lab File No.	: >L6787
		Method Blank No.	: RB082093

008503

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Chloromethane	74-87-3	U	1.0
Bromomethane	74-83-9	U	1.0
Vinyl Chloride	75-01-4	U	1.0
Chloroethane	75-00-3	U	1.0
Methylene Chloride	75-09-2	U	1.0
Acetone	67-64-1	15	10.0
Carbon Disulfide	75-15-0	U	1.0
1,1-Dichloroethene	75-35-4	U	1.0
1,1-Dichloroethane	75-34-3	U	1.0
Trans-1,2-Dichloroethene	156-60-5	U	2.0
Chloroform	67-66-3	U	1.0
1,2-Dichloroethane	107-06-2	U	1.0
2-Butanone	78-93-3	U	10.0
1,1,1-Trichloroethane	71-55-6	U	0.5
Carbon Tetrachloride	56-23-5	U	2.0
Bromodichloromethane	75-27-4	U	1.0
Vinyl Acetate	108-05-4	U	10.0
1,2-Dichloropropane	78-87-5	U	1.0
Trans-1,3-Dichloropropene	10061-02-6	U	2.0
Trichloroethene	79-01-6	U	1.0
1,2-Trichloroethane	79-00-5	U	1.0
Benzene	71-43-2	4 X	0.5
Bromochloromethane	124-48-1	U	1.0
Cis-1,3-Dichloropropene	10061-01-5	U	1.0
2-Chloroethylvinyl Ether	110-75-8	U	5.0
Bromoform	75-25-2	U	1.0
4-Methyl-2-Pentanone	108-10-1	U	5.0
2-Hexanone	591-78-6	U	5.0
1,1,2,2-Tetrachloroethane	79-34-5	U	1.0
Tetrachloroethene	127-18-4	U	1.0
Toluene	108-88-3	1 X	0.5
Chlorobenzene	108-90-7	4 X	1.0
Ethyl Benzene	100-41-4	U	0.5
Styrene	100-42-5	U	1.0
Total Xylenes	1330-20-7	U	0.5
Trichlorofluoromethane	75-69-4	U	0.5

Surrogate Recoveries:

1,2 Dichloroethane-d4	104%	(87-109)
Toluene-d8	95%	(88-110)
Bromofluorobenzene	112%	(89-111)

QUALIFIERS:

X = Analytes present in blank analyzed on the same day. See duplicate.  
U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	: 46836	Client I.D.	: 8068
Lab Sample Number	: X74795	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93	Effective Dilution	: 1.00
Date Received	: 08/07/93	Method	: 624
Date Extracted/Prepared	: 08/20/93	Matrix	: WATER
Date Analyzed	: 08/20/93	Lab File No.	: >L6787
		Method Blank No.	: RB082093

008504

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Benzene	71-43-2	4 X	0.5
Toluene	108-88-3	1 X	0.5
Ethyl Benzene	100-41-4	U	0.5
Total Xylenes	1330-20-7	U	0.5

Surrogate Recoveries:

1,2 Dichloroethane-d4	104%
Toluene-d8	95%
Bromofluorobenzene	112%

QC Limits

(87-109)
(88-110)
(89-111)

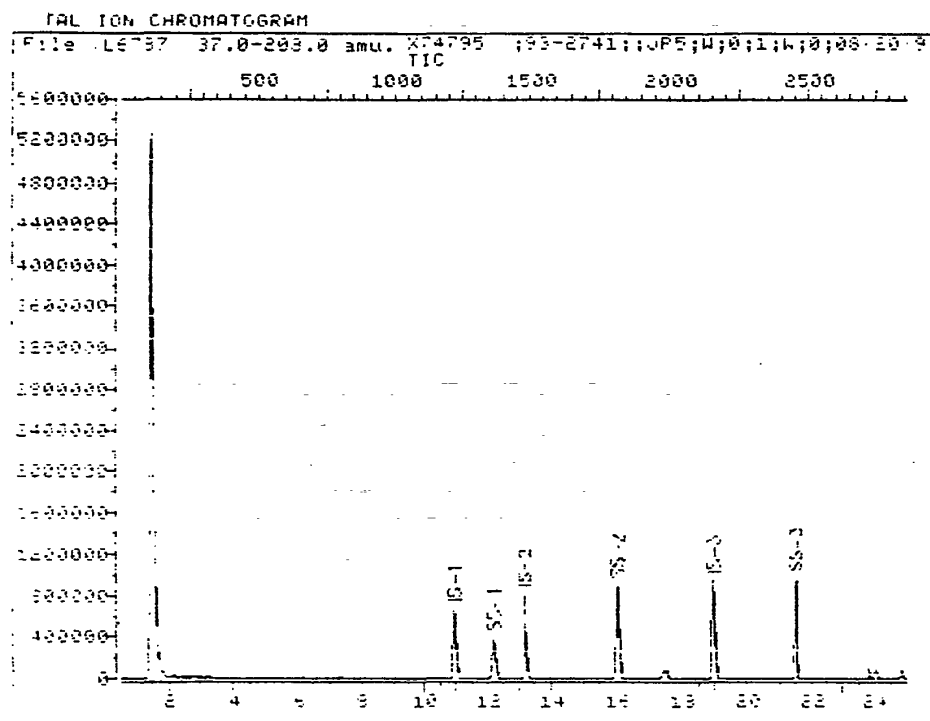
QUALIFIERS:

X = Analytes present in blank analyzed on the same day. See duplicate.  
U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

008505



Data File: L6797:001  
Name: X74795 ;93-2741::JP  
Mass: 510;0;1;0;0;08-20-93;0

Client Output File: L6797:01  
Instrument ID: 459LHN

Id File: IC\_0061:0T  
Title: IC FILE FOR 400SEP MET400 61-  
Last Calibration: 930916 13:43

Last Calibration: none

Operator ID: JCH  
Quant Time : 030020 16:22  
Injected at: 030020 16:55

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

VOLATILE ORGANICS ANALYSIS DATA  
Target Compound List

Client Sample Number	: 46836	DUPLICATE	Client I.D.	: 8068
Lab Sample Number	: X74795	DUP	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93		Effective Dilution	: 1.00
Date Received	: 08/07/93		Method	: 624
Date Extracted/Prepared	: 08/24/93		Matrix	: WATER
Date Analyzed	: 08/24/93		Lab File No.	: >L6817
			Method Blank No.	: RB082493

008506

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Chloromethane	74-87-3	U	1.0
Bromomethane	74-83-9	U	1.0
Vinyl Chloride	75-01-4	U	1.0
Chloroethane	75-00-3	U	1.0
Methylene Chloride	75-09-2	U	1.0
Acetone	67-64-1	32 B	10.0
Carbon Disulfide	75-15-0	1	1.0
1,1-Dichloroethene	75-35-4	U	1.0
1,1-Dichloroethane	75-34-3	U	1.0
Trans-1,2-Dichloroethene	156-60-5	U	2.0
Chloroform	67-66-3	U	1.0
1,2-Dichloroethane	107-06-2	U	1.0
2-Butanone	78-93-3	U	10.0
1,1,1-Trichloroethane	71-55-6	U	0.5
Carbon Tetrachloride	56-23-5	U	2.0
Bromodichloromethane	75-27-4	U	1.0
Vinyl Acetate	108-05-4	U	10.0
1,2-Dichloropropane	78-87-5	U	1.0
Trans-1,3-Dichloropropene	10061-02-6	U	2.0
Trichloroethene	79-01-6	U	1.0
1,2-Trichloroethane	79-00-5	U	1.0
Benzene	71-43-2	U	0.5
Bromochloromethane	124-48-1	U	1.0
Cis-1,3-Dichloropropene	10061-01-5	U	1.0
2-Chloroethylvinyl Ether	110-75-8	U	5.0
Bromoform	75-25-2	U	1.0
4-Methyl-2-Pentanone	108-10-1	U	5.0
2-Hexanone	591-78-6	U	5.0
1,1,2,2-Tetrachloroethane	79-34-5	U	1.0
Tetrachloroethene	127-18-4	U	1.0
Toluene	108-88-3	1	0.5
Chlorobenzene	108-90-7	U	1.0
Ethyl Benzene	100-41-4	U	0.5
Styrene	100-42-5	U	1.0
Total Xylenes	1330-20-7	U	0.5
Trichlorofluoromethane	75-69-4	U	0.5

Surrogate Recoveries:

1,2 Dichloroethane-d4	92%	(87-109)
Toluene-d8	97%	(88-110)
Bromofluorobenzene	100%	(89-111)

QUALIFIERS:

U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved



EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number : 46836 DUPLICATE  
Lab Sample Number : X74795 DUP  
Date Sampled : 08/06/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/24/93  
Date Analyzed : 08/24/93  
Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 624  
Matrix : WATER  
Lab File No. : >L6817  
Method Blank No. : RB082493

008507

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Benzene	71-43-2	U	0.5
Toluene	108-88-3	1	0.5
Ethyl Benzene	100-41-4	U	0.5
Total Xylenes	1330-20-7	U	0.5

Surrogate Recoveries:

QC Limits

1,2 Dichloroethane-d4	92%	(87-109)
Toluene-d8	97%	(88-110)
Bromofluorobenzene	100%	(89-111)

QUALIFIERS:

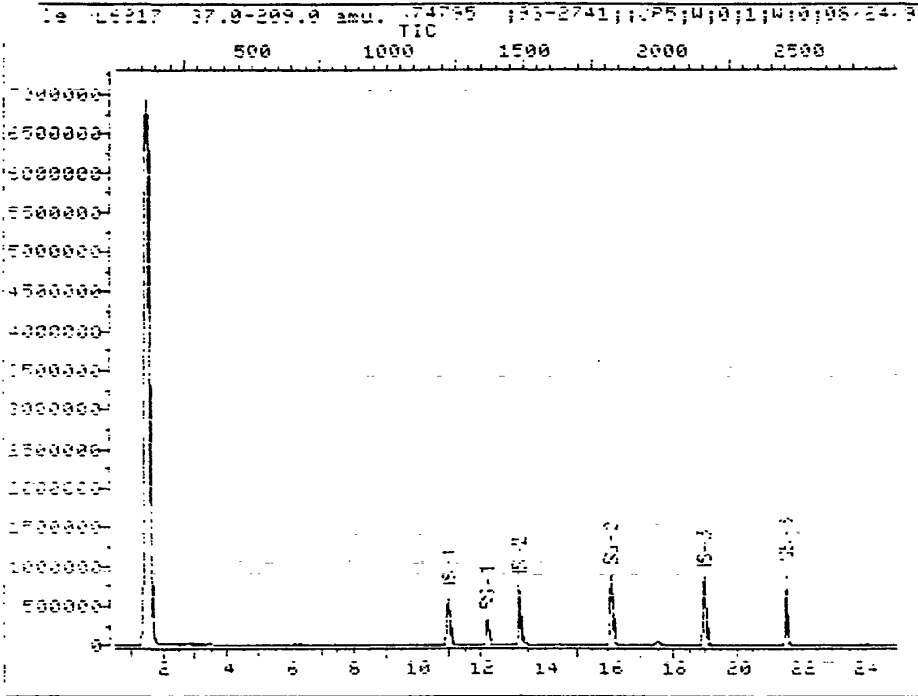
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NA = Not applicable or not available.

Analyst

Approved

008508

TOTAL ION CHROMATOGRAM



Data File: 06917:01  
Name: 06917:01  
Misc: 5:10:01;M:10:02 24-93:0

Quant Output File: 06917:01  
Instrument: 12: 4801A

In File: 00000:01  
Title: 12 FILE 00000000000000000000  
Last Calibration: 06917:01:01

Last Test Time: 06917:01:01

Operator ID: 0000  
Plant Time: 06917:01:01  
Injected at: 06917:01:01

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA  
Target Compound List

Client Sample Number : 2136-64  
Lab Sample Number : X74796  
Date Sampled : 08/07/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/20/93  
Date Analyzed : 08/20/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 624  
Matrix : WATER  
Lab File No. : >L6788  
Method Blank No. : RB082093

008509

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Chloromethane	74-87-3	U	1.0
Bromomethane	74-83-9	U	1.0
Vinyl Chloride	75-01-4	U	1.0
Chloroethane	75-00-3	U	1.0
Methylene Chloride	75-09-2	U	1.0
Acetone	67-64-1	460	10.0
Carbon Disulfide	75-15-0	2	1.0
1,1-Dichloroethene	75-35-4	U	1.0
1,1-Dichloroethane	75-34-3	U	1.0
Trans-1,2-Dichloroethene	156-60-5	U	2.0
Chloroform	67-66-3	U	1.0
1,2-Dichloroethane	107-06-2	U	1.0
2-Butanone	78-93-3	U	10.0
1,1,1-Trichloroethane	71-55-6	U	0.5
Carbon Tetrachloride	56-23-5	U	0.5
Bromodichloromethane	75-27-4	U	1.0
Vinyl Acetate	108-05-4	U	10.0
1,2-Dichloropropane	78-87-5	U	1.0
Trans-1,3-Dichloropropene	10061-02-6	U	2.0
Trichloroethene	79-01-6	U	1.0
1,1,2-Trichloroethane	79-00-5	U	1.0
Perfluorobenzene	71-43-2	U	0.5
Dibromochloromethane	124-48-1	U	1.0
Cis-1,3-Dichloropropene	10061-01-5	U	1.0
2-Chloroethylvinyl Ether	110-75-8	U	5.0
Bromoform	75-25-2	U	1.0
4-Methyl-2-Pentanone	108-10-1	U	5.0
2-Hexanone	591-78-6	U	5.0
1,1,2,2-Tetrachloroethane	79-34-5	U	1.0
Tetrachloroethene	127-18-4	U	1.0
Toluene	108-88-3	U	0.5
Chlorobenzene	108-90-7	U	1.0
Ethyl Benzene	100-41-4	U	0.5
Styrene	100-42-5	U	1.0
Total Xylenes	1330-20-7	U	0.5
Trichlorofluoromethane	75-69-4	U	0.5

Surrogate Recoveries:

1,2 Dichloroethane-d4 105%  
Toluene-d8 98%  
Bromofluorobenzene 107%

QC Limits

(87-109)  
(88-110)  
(89-111)

QUALIFIERS:

U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number : 2136-64  
Lab Sample Number : X74796  
Date Sampled : 08/07/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/20/93  
Date Analyzed : 08/20/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 624  
Matrix : WATER  
Lab File No. : >L6788  
Method Blank No. : RB082093

008510

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Benzene	71-43-2	U	0.5
Toluene	108-88-3	U	0.5
Ethyl Benzene	100-41-4	U	0.5
Total Xylenes	1330-20-7	U	0.5

Surrogate Recoveries:


1,2 Dichloroethane-d4 105%  
Toluene-d8 98%  
Bromofluorobenzene 107%

QC Limits

(87-109)  
(88-110)  
(89-111)

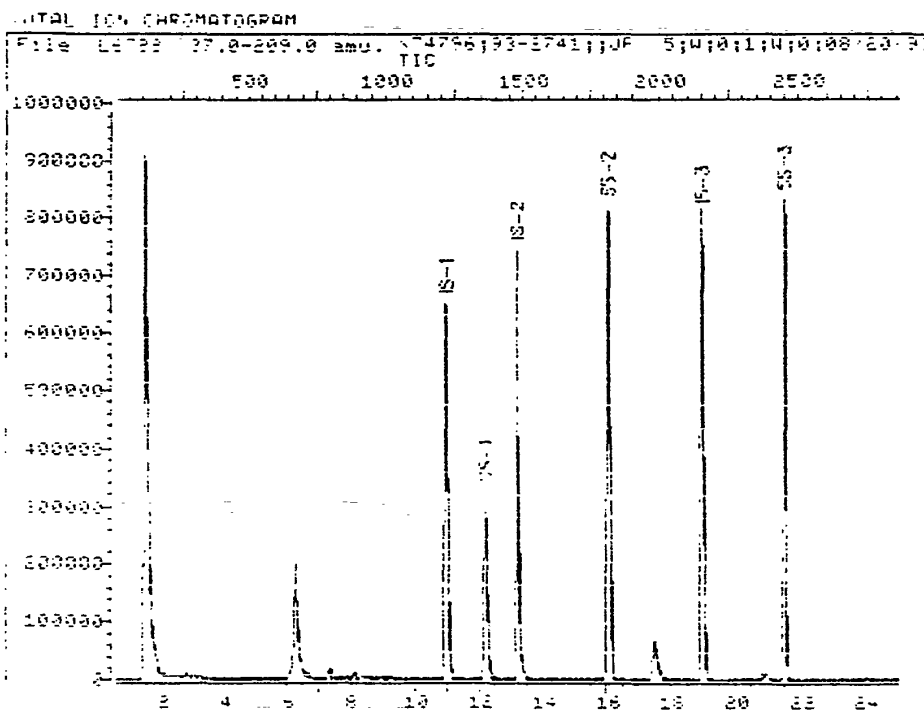
QUALIFIERS:

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B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

  
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Analyst

  
\_\_\_\_\_  
Approved

008511



Data File: L6786  
 Name: L6786;93-1741;JF  
 Misc: 5;U;0;1;U;0;08-20-93;0

Quant Output File: L6786;01  
 Instrument: 10; \*JULIAN

Id File: ID L6786;01  
 Title: ID FILE FOR 400MHz METHAC  
 Last Calibration: 930912 17:49

Last Eval Time: None

Operator ID: JCH  
 Quant Time: 930820 16:51  
 Injected at: 930820 16:21

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

METHOD BLANK REPORT

Target Compound List

Method Blank Number : RB082093 Client I.D. : 8068  
Date Extracted/Prepared : 08/20/93 Lab Project No. : 93-2741  
Date Analyzed : 08/20/93 Effective Dilution : 1.00  
Method : 624  
Lab File No. : >L6786

008512

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Chloromethane	74-87-3	U	1.0
Bromomethane	74-83-9	U	1.0
Vinyl Chloride	75-01-4	U	1.0
Chloroethane	75-00-3	U	1.0
Methylene Chloride	75-09-2	U	1.0
Acetone	67-64-1	U	10.0
Carbon Disulfide	75-15-0	U	1.0
1,1-Dichloroethene	75-35-4	U	1.0
1,1-Dichloroethane	75-34-3	U	1.0
Trans-1,2-Dichloroethene	156-60-5	U	2.0
Chloroform	67-66-3	1	1.0
1,2-Dichloroethane	107-06-2	U	1.0
2-Butanone	78-93-3	U	10.0
1,1,1-Trichloroethane	71-55-6	U	0.5
Carbon Tetrachloride	56-23-5	U	2.0
Bromodichloromethane	75-27-4	U	1.0
Vinyl Acetate	108-05-4	U	10.0
1,2-Dichloropropane	78-87-5	U	1.0
Trans-1,3-Dichloropropene	10061-02-6	U	2.0
Trichloroethene	79-01-6	U	1.0
1,1,2-Trichloroethane	79-00-5	U	1.0
Benzene	71-43-2	U	0.5
Bromochloromethane	124-48-1	U	1.0
Cis-1,3-Dichloropropene	10061-01-5	U	1.0
2-Chloroethylvinyl Ether	110-75-8	U	5.0
Bromoform	75-25-2	U	1.0
4-Methyl-2-Pentanone	108-10-1	U	5.0
2-Hexanone	591-78-6	U	5.0
1,1,2,2-Tetrachloroethane	79-34-5	U	1.0
Tetrachloroethene	127-18-4	U	1.0
Toluene	108-88-3	U	0.5
Chlorobenzene	108-90-7	U	1.0
Ethyl Benzene	100-41-4	U	0.5
Styrene	100-42-5	U	1.0
Total Xylenes	1330-20-7	U	0.5
Trichlorofluoromethane	75-69-4	U	0.5

Surrogate Recoveries:

1,2 Dichloroethane-d4 105%  
Toluene-d8 97%  
Bromofluorobenzene 111%

QC Limits

(87-109)  
(88-110)  
(89-111)

QUALIFIERS:

U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
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E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

VOLATILE ORGANICS ANALYSIS DATA  
METHOD BLANK REPORT

Method Blank Number	: RB082093	Client I.D.	: 8068
Date Extracted/Prepared	: 08/20/93	Lab Project No.	: 93-2741
Date Analyzed	: 08/20/93	Effective Dilution	: 1.00
		Method	: 624
		Lab File No.	: >L6786

008513

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Benzene	71-43-2	U	0.5
Toluene	108-88-3	U	0.5
Ethyl Benzene	100-41-4	U	0.5
Total Xylenes	1330-20-7	U	0.5

Surrogate Recoveries:


1,2 Dichloroethane-d4	105%
Toluene-d8	97%
Bromofluorobenzene	111%

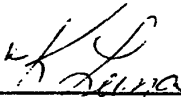
QC Limits

(87-109)
(88-110)
(89-111)

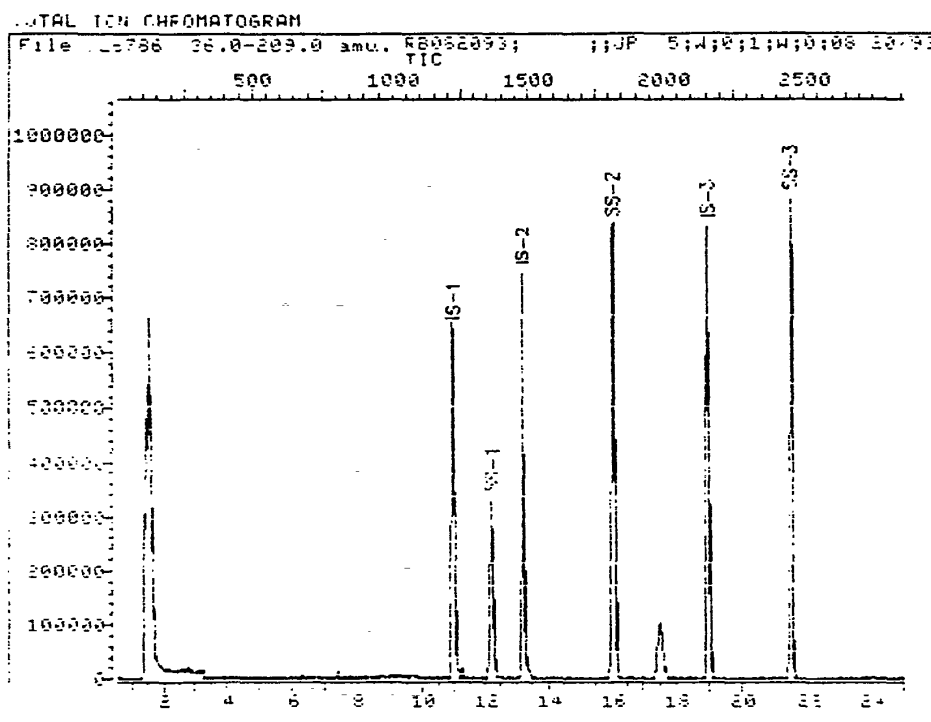
QUALIFIERS:

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B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

  
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Analyst

  
\_\_\_\_\_  
Approved

008514



Data File: L6786:01  
Name: R6052093; ;JP  
File: 5;4;0;1;4;0;08 10-93;0

Client Output File: L6786:01  
Instrument ID: \*MSLAN

Id File: ID00000001  
Title: ID00000001  
Last Calibration: 07/01/93 17:43

Method: 014  
Last Deal Time: 0000

Operator ID: 000000  
Start Time: 000000 10:38  
Injected at: 000000 10:01



EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

METHOD BLANK REPORT

Target Compound List

Method Blank Number : RB082493 Client I.D. : 8068  
Date Extracted/Prepared : 08/24/93 Lab Project No. : 93-2741  
Date Analyzed : 08/24/93 Effective Dilution : 1.00  
Method : 624  
Lab File No. : >L6816

008515

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Chloromethane	74-87-3	U	1.0
Bromomethane	74-83-9	U	1.0
Vinyl Chloride	75-01-4	U	1.0
Chloroethane	75-00-3	U	1.0
Methylene Chloride	75-09-2	U	1.0
Acetone	67-64-1	12	10.0
Carbon Disulfide	75-15-0	U	1.0
1,1-Dichloroethene	75-35-4	U	1.0
1,1-Dichloroethane	75-34-3	U	1.0
Trans-1,2-Dichloroethene	156-60-5	U	2.0
Chloroform	67-66-3	U	1.0
1,2-Dichloroethane	107-06-2	U	1.0
2-Butanone	78-93-3	U	10.0
1,1,1-Trichloroethane	71-55-6	U	0.5
Carbon Tetrachloride	56-23-5	U	2.0
Bromodichloromethane	75-27-4	U	1.0
Vinyl Acetate	108-05-4	U	10.0
1,2-Dichloropropane	78-87-5	U	1.0
Trans-1,3-Dichloropropene	10061-02-6	U	2.0
Trichloroethene	79-01-6	U	1.0
1,2-Trichloroethane	79-00-5	U	1.0
Azene	71-43-2	U	0.5
Dibromochloromethane	124-48-1	U	1.0
Cis-1,3-Dichloropropene	10061-01-5	U	1.0
2-Chloroethylvinyl Ether	110-75-8	U	5.0
Bromoform	75-25-2	U	1.0
4-Methyl-2-Pentanone	108-10-1	U	5.0
2-Hexanone	591-78-6	U	5.0
1,1,2,2-Tetrachloroethane	79-34-5	U	1.0
Tetrachloroethene	127-18-4	U	1.0
Toluene	108-88-3	U	0.5
Chlorobenzene	108-90-7	1	1.0
Ethyl Benzene	100-41-4	U	0.5
Styrene	100-42-5	U	1.0
Total Xylenes	1330-20-7	U	0.5
Trichlorofluoromethane	75-69-4	U	0.5

Surrogate Recoveries:

QC Limits

1,2 Dichloroethane-d4 96%  
Toluene-d8 97%  
Bromofluorobenzene 102%

(87-109)  
(88-110)  
(89-111)

QUALIFIERS:

U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA  
METHOD BLANK REPORT

Method Blank Number	: RB082493	Client I.D.	: 8068
Date Extracted/Prepared	: 08/24/93	Lab Project No.	: 93-2741
Date Analyzed	: 08/24/93	Effective Dilution	: 1.00
		Method	: 624
		Lab File No.	: >L6816

008516

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Benzene	71-43-2	U	0.5
Toluene	108-88-3	U	0.5
Ethyl Benzene	100-41-4	U	0.5
Total Xylenes	1330-20-7	U	0.5

Surrogate Recoveries:


1,2 Dichloroethane-d4	96%
Toluene-d8	97%
Bromofluorobenzene	102%

QC Limits

(87-109)
(88-110)
(89-111)

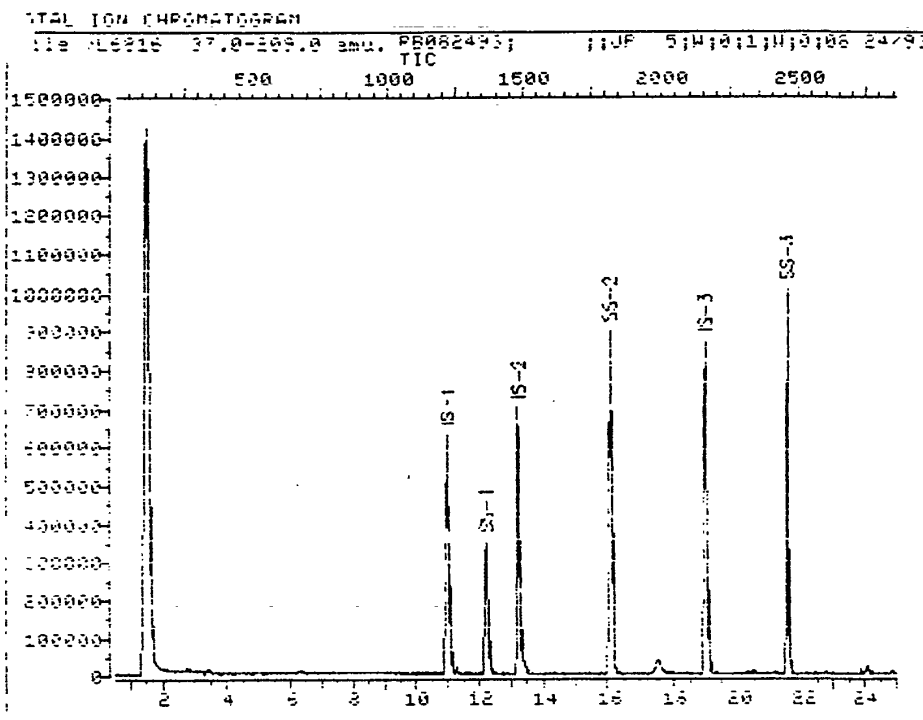
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B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

  
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Analyst

  
\_\_\_\_\_  
Approved

008517



Date: 05/14/01 11:00:06  
 Name: 008216  
 File: 008216 37.0-169.0 amu. PB082493; 11:00 5/14/01 11:00:06 24/93:0

Client Output File: 008216:01  
 Instrument ID: 11000000

File: 008216:01  
 File: 008216:01  
 Last Calibration: 008216 14:00:00 01-

Last Occ: Time: none

Operator: 11: 0041  
 Start Time: 008216 10:00  
 Projected at: 008216 11:42

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

VOLATILE ORGANICS ANALYSIS DATA  
Target Compound List

Client Sample Number	: 46836 MS	Client I.D.	: 8068
Sample Number	: X74795MS	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93	Effective Dilution	: 1.00
Date Received	: 08/07/93	Method	: 624
Date Extracted/Prepared	: 08/20/93	Matrix	: WATER
Date Analyzed	: 08/20/93	Lab File No.	: >L6793
		Method Blank No.	: RB082093

008518

Compound Name	Cas Number	Conc. ug/L	REC %
Chloromethane	74-87-3	29	58%
Bromomethane	74-83-9	45	91%
Vinyl Chloride	75-01-4	36	72%
Chloroethane	75-00-3	47	93%
Methylene Chloride	75-09-2	57	115%
Acetone	67-64-1	85	170%
Carbon Disulfide	75-15-0	46	92%
1,1-Dichloroethene	75-35-4	49	99%
1,1-Dichloroethane	75-34-3	54	108%
Trans-1,2-Dichloroethene	156-60-5	54	108%
Chloroform	67-66-3	49	99%
1,2-Dichloroethane	107-06-2	56	111%
2-Butanone	78-93-3	110	220%
1,1,1-Trichloroethane	71-55-6	56	113%
Carbon Tetrachloride	56-23-5	55	110%
Bromodichloromethane	75-27-4	66	131%
Vinyl Acetate	108-05-4	74	147%
1,2-Dichloropropane	78-87-5	67	134%
Trans-1,3-Dichloropropene	10061-02-6	64	128%
Trichloroethene	79-01-6	65	129%
1,2-Trichloroethane	79-00-5	77	154%
Isene	71-43-2	55	110%
1-bromochloromethane	124-48-1	70	141%
Cis-1,3-Dichloropropene	10061-01-5	83	165%
2-Chloroethylvinyl Ether	110-75-8		0%
Bromoform	75-25-2	77	153%
4-Methyl-2-Pentanone	108-10-1	60	120%
2-Hexanone	591-78-6	66	132%
1,1,2,2-Tetrachloroethane	79-34-5	49	98%
Tetrachloroethene	127-18-4	43	86%
Toluene	108-88-3	46	93%
Chlorobenzene	108-90-7	47	94%
Ethyl Benzene	100-41-4	48	96%
Styrene	100-42-5	55	110%
Total Xylenes	1330-20-7	46	93%
Trichlorofluoromethane	75-69-4	48	96%

Surrogate Recoveries:

1,2 Dichloroethane-d4	121%
Toluene-d8	102%
Bromofluorobenzene	121%

QC Limits

(85-114)
(90-110)
(86-112)

QUALIFIERS:

NS = Not spiked.  
U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	: 46836 MS	Client I.D.	: 8068
Lab Sample Number	: X74795MS	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93	Effective Dilution	: 1.00
Date Received	: 08/07/93	Method	: 624
Date Extracted/Prepared	: 08/20/93	Matrix	: WATER
Date Analyzed	: 08/20/93	Lab File No.	: >L6793
		Method Blank No.	: RB082093

Compound Name	Cas Number	Conc. ug/L	REC %
Benzene	71-43-2	55	110%
Toluene	108-88-3	46	93%
Ethyl Benzene	100-41-4	48	96%
Total Xylenes	1330-20-7	46	93%

Surrogate Recoveries:

1,2 Dichloroethane-d4	121%
Toluene-d8	102%
Bromofluorobenzene	121%

QC Limits

(85-114)
(90-110)
(86-112)

QUALIFIERS:

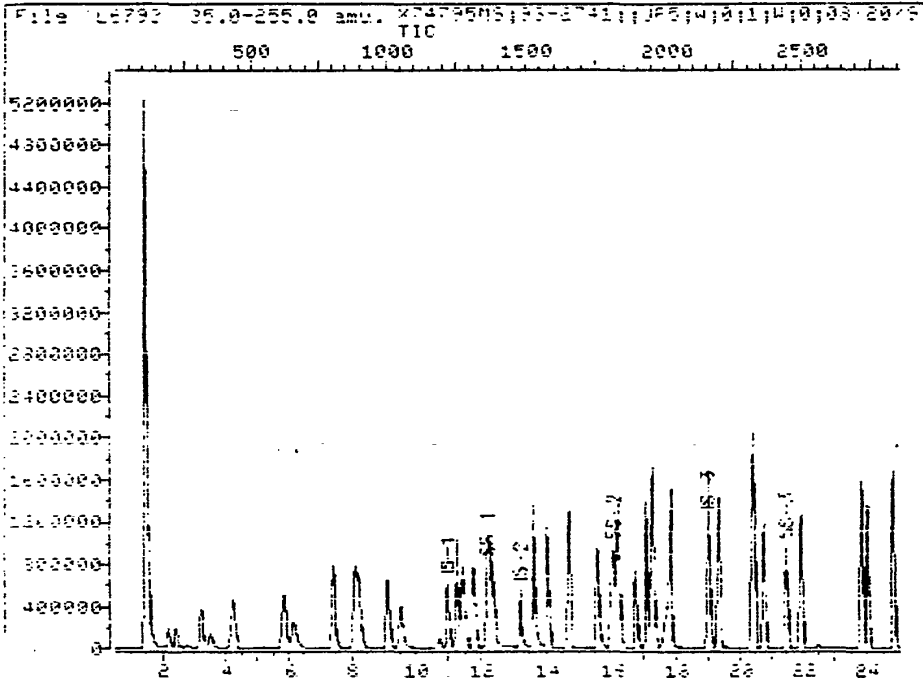
NS = Not spiked.  
U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
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NA = Not applicable or not available.

Analyst

Approved

008520

## TOTAL ION CHROMATOGRAM



Data File: L4793  
Name: X47995MS;93-11-11;J25;4;0;1;4;0;03-20-93  
Time: 9:00:01;00:00:00 20 07:07  
Quant Output File: L4793;01  
Instrument ID: 008520  
ID File: ID.U25;07  
Title: ID FILE FOR 40000 03-11-93 01  
Last Calibration: 930812 13:13  
Last Cal Time: None  
Operator ID: JOHN  
Quant Time : 930820 21:07  
Injected at: 930820 20:32

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA  
Target Compound List

Client Sample Number	: 624 REF	Client I.D.	: 8068
Lab Sample Number	: 624 REF	Lab Project No.	: 93-2741
Date Sampled	: NA	Effective Dilution	: 1.00
Date Received	: NA	Method	: 624
Date Extracted/Prepared	: 08/20/93	Matrix	: WATER
Date Analyzed	: 08/20/93	Lab File No.	: >L6794
		Method Blank No.	: RB082093

008521

Compound Name	Cas Number	Conc. ug/L	REC %
Chloromethane	74-87-3	26	53%
Bromomethane	74-83-9	46	92%
Vinyl Chloride	75-01-4	37	73%
Chloroethane	75-00-3	47	95%
Methylene Chloride	75-09-2	59	117%
Acetone	67-64-1	40	80%
Carbon Disulfide	75-15-0	46	92%
1,1-Dichloroethene	75-35-4	52	104%
1,1-Dichloroethane	75-34-3	56	112%
Trans-1,2-Dichloroethene	156-60-5	55	110%
Chloroform	67-66-3	52	104%
1,2-Dichloroethane	107-06-2	56	112%
2-Butanone	78-93-3	88	176%
1,1,1-Trichloroethane	71-55-6	57	114%
Carbon Tetrachloride	56-23-5	55	110%
Bromodichloromethane	75-27-4	66	131%
Vinyl Acetate	108-05-4	76	153%
1,2-Dichloropropane	78-87-5	68	135%
Trans-1,3-Dichloropropene	10061-02-6	64	128%
Trichloroethene	79-01-6	64	128%
1,1,2-Trichloroethane	79-00-5	76	153%
Benzene	71-43-2	56	111%
Dibromochloromethane	124-48-1	71	141%
Cis-1,3-Dichloropropene	10061-01-5	82	165%
2-Chloroethylvinyl Ether	110-75-8	86	173%
Bromoform	75-25-2	75	151%
4-Methyl-2-Pentanone	108-10-1	55	110%
2-Hexanone	591-78-6	61	123%
1,1,2,2-Tetrachloroethane	79-34-5	48	97%
Tetrachloroethene	127-18-4	43	86%
Toluene	108-88-3	47	93%
Chlorobenzene	108-90-7	48	96%
Ethyl Benzene	100-41-4	49	97%
Styrene	100-42-5	57	113%
Total Xylenes	1330-20-7	47	94%
Trichlorofluoromethane	75-69-4	48	97%

Surrogate Recoveries:

1,2 Dichloroethane-d4	124%
Toluene-d8	101%
Bromofluorobenzene	120%

QC Limits

(85-114)
(90-110)
(86-112)

QUALIFIERS:

NS = Not spiked.  
U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number : 624 REF  
Lab Sample Number : 624 REF  
Date Sampled : NA  
Date Received : NA  
Date Extracted/Prepared : 08/20/93  
Date Analyzed : 08/20/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 624  
Matrix : WATER  
Lab File No. : >L6794  
Method Blank No. : RB082093

008522

Compound Name	Cas Number	Conc. ug/L	REC %
Benzene	71-43-2	56	111%
Toluene	108-88-3	47	93%
Ethyl Benzene	100-41-4	49	97%
Total Xylenes	1330-20-7	47	94%

Surrogate Recoveries:


1,2 Dichloroethane-d4 124%  
Toluene-d8 101%  
Bromofluorobenzene 120%

QC Limits

(85-114)  
(90-110)  
(86-112)

QUALIFIERS:

NS = Not spiked.  
U = Compound analyzed for, but not detected above the reporting limit.  
B = Compound found in blank and sample. Compare blank and sample data.  
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E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

  
\_\_\_\_\_  
Analyst

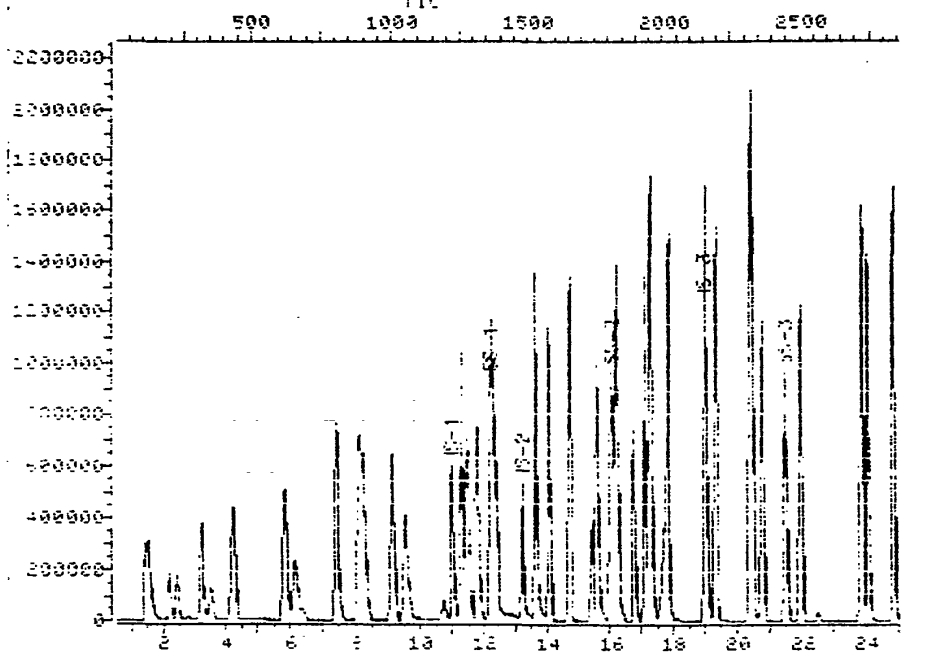
  
\_\_\_\_\_  
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008523

## TOTAL ION CHROMATOGRAM

File: 46794 35.0-255.0 amu. 0.1 REF 1:JP5;4;0;1;4;0;06 20-93



Data File: 46794:01  
 Name: 10-2  
 Misc: 35.0-255.0 amu. 0.1 REF 1:JP5;4;0;1;4;0;06 20-93

Quant Output File: 46794:01  
 Instrument ID: 46794

Id File: 10-2:01  
 Title: 10-2  
 Last Calibration: 9/20/93 10:13

Last Cal Time: none

Operator ID: JOHN  
 Quant Time: 9/20/93 21:40  
 Injected at: 9/20/93 21:13

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

VOLATILE ORGANICS ANALYSIS DATA  
Target Compound List

ient Sample Number	: 46836 MS	Client I.D.	: 8068
o Sample Number	: X74795MS	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93	Effective Dilution	: 1.00
Date Received	: 08/07/93	Method	: 624
Date Extracted/Prepared	: 08/24/93	Matrix	: WATER
Date Analyzed	: 08/24/93	Lab File No.	: >L6819
		Method Blank No.	: RB082493

008524

Compound Name	Cas Number	Conc. ug/L	REC %
Chloromethane	74-87-3	24	118%
Bromomethane	74-83-9	24	118%
Vinyl Chloride	75-01-4	23	117%
Chloroethane	75-00-3	23	113%
Methylene Chloride	75-09-2	23	115%
Acetone	67-64-1	27 B	136%
Carbon Disulfide	75-15-0	42	209%
1,1-Dichloroethene	75-35-4	23	115%
1,1-Dichloroethane	75-34-3	22	111%
Trans-1,2-Dichloroethene	156-60-5	22	109%
Chloroform	67-66-3	22	110%
1,2-Dichloroethane	107-06-2	20	102%
2-Butanone	78-93-3	U	0%
1,1,1-Trichloroethane	71-55-6	19	93%
Carbon Tetrachloride	56-23-5	17	83%
Bromodichloromethane	75-27-4	19	95%
Vinyl Acetate	108-05-4	13	64%
1,2-Dichloropropane	78-87-5	20	100%
Trans-1,3-Dichloropropene	10061-02-6	15	75%
Trichloroethene	79-01-6	19	97%
1,2-Trichloroethane	79-00-5	18	90%
nzene	71-43-2	20	98%
ibromochloromethane	124-48-1	17	83%
Cis-1,3-Dichloropropene	10061-01-5	22	111%
2-Chloroethylvinyl Ether	110-75-8	9	45%
Bromoform	75-25-2	15	73%
4-Methyl-2-Pentanone	108-10-1	19	93%
2-Hexanone	591-78-6	16	80%
1,1,2,2-Tetrachloroethane	79-34-5	19	93%
Tetrachloroethene	127-18-4	19	96%
Toluene	108-88-3	21	104%
Chlorobenzene	108-90-7	20 B	100%
Ethyl Benzene	100-41-4	20	98%
Styrene	100-42-5	22	110%
Total Xylenes	1330-20-7	21	107%
Trichlorofluoromethane	75-69-4	23	115%

Surrogate Recoveries:

1,2 Dichloroethane-d4	99%
Toluene-d8	102%
Bromofluorobenzene	105%

QC Limits

(85-114)
(90-110)
(86-112)

QUALIFIERS:

NS = Not spiked.  
U = Compound analyzed for, but not detected above the reporting limit.  
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E = Compound is detected but concentration is outside of calibration limits.  
NA = Not applicable or not available.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	: 46836 MS	Client I.D.	: 8068
Lab Sample Number	: X74795MS	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93	Effective Dilution	: 1.00
Date Received	: 08/07/93	Method	: 624
Date Extracted/Prepared	: 08/24/93	Matrix	: WATER
Date Analyzed	: 08/24/93	Lab File No.	: >L6819
		Method Blank No.	: RB082493

Compound Name	Cas Number	Conc. ug/L	REC %
Benzene	71-43-2	20	98%
Toluene	108-88-3	21	104%
Ethyl Benzene	100-41-4	20	98%
Total Xylenes	1330-20-7	21	107%

Surrogate Recoveries:

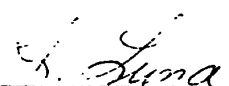
QC Limits

1,2 Dichloroethane-d4	99%	(85-114)
Toluene-d8	102%	(90-110)
Bromofluorobenzene	105%	(86-112)

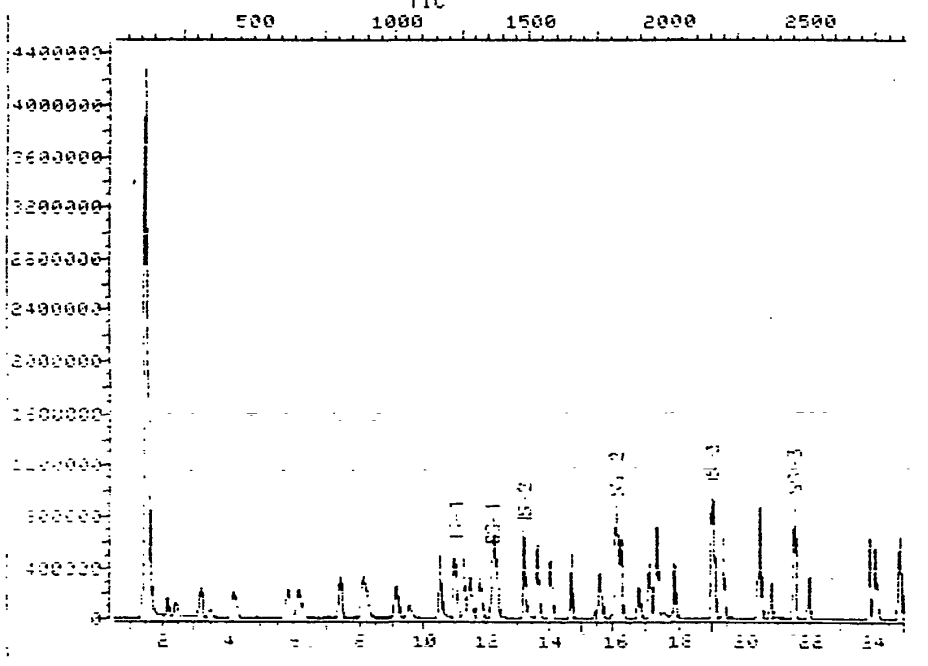
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NA = Not applicable or not available.

  
\_\_\_\_\_  
Analyst

  
\_\_\_\_\_  
Approved

008525



Last Deal Type: none

[illegible]

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

VOLATILE ORGANICS ANALYSIS DATA  
Target Compound List

Client Sample Number : 624 REF  
Lab Sample Number : 624 REF  
Date Sampled : NA  
Date Received : NA  
Date Extracted/Prepared : 08/24/93  
Date Analyzed : 08/24/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 624  
Matrix : WATER  
Lab File No. : >L6820  
Method Blank No. : RB082493

008527

Compound Name	Cas Number	Conc. ug/L	REC %
Chloromethane	74-87-3	21	105%
Bromomethane	74-83-9	21	105%
Vinyl Chloride	75-01-4	21	106%
Chloroethane	75-00-3	20	100%
Methylene Chloride	75-09-2	20	102%
Acetone	67-64-1	22 B	108%
Carbon Disulfide	75-15-0	36	180%
1,1-Dichloroethene	75-35-4	20	102%
1,1-Dichloroethane	75-34-3	20	102%
Trans-1,2-Dichloroethene	156-60-5	19	97%
Chloroform	67-66-3	21	106%
1,2-Dichloroethane	107-06-2	20	100%
2-Butanone	78-93-3	U	0%
1,1,1-Trichloroethane	71-55-6	19	93%
Carbon Tetrachloride	56-23-5	17	85%
Bromodichloromethane	75-27-4	20	101%
Vinyl Acetate	108-05-4	15	77%
1,2-Dichloropropane	78-87-5	21	105%
Trans-1,3-Dichloropropene	10061-02-6	16	79%
Trichloroethene	79-01-6	20	98%
1,2-Trichloroethane	79-00-5	21	103%
Benzene	71-43-2	19	95%
Dibromochloromethane	124-48-1	18	92%
Cis-1,3-Dichloropropene	10061-01-5	23	113%
2-Chloroethylvinyl Ether	110-75-8	18	88%
Bromoform	75-25-2	18	91%
4-Methyl-2-Pentanone	108-10-1	24	122%
2-Hexanone	591-78-6	23	115%
1,1,2,2-Tetrachloroethane	79-34-5	22	109%
Tetrachloroethene	127-18-4	19	97%
Toluene	108-88-3	20	99%
Chlorobenzene	108-90-7	19 B	97%
Ethyl Benzene	100-41-4	20	98%
Styrene	100-42-5	22	109%
Total Xylenes	1330-20-7	21	107%
Trichlorofluoromethane	75-69-4	20	102%

Surrogate Recoveries:

1,2 Dichloroethane-d4 102%  
Toluene-d8 101%  
Bromofluorobenzene 105%

QC Limits

(85-114)  
(90-110)  
(86-112)

QUALIFIERS:

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Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number : 624 REF  
Lab Sample Number : 624 REF  
Date Sampled : 08/06/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/24/93  
Date Analyzed : 08/24/93  
Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 624  
Matrix : WATER  
Lab File No. : >L6820  
Method Blank No. : RB082493

008528

Compound Name	Cas Number	Conc. ug/L	REC %
Benzene	71-43-2	19	95%
Toluene	108-88-3	20	99%
Ethyl Benzene	100-41-4	20	98%
Total Xylenes	1330-20-7	21	107%

Surrogate Recoveries:

1,2 Dichloroethane-d4 102%  
Toluene-d8 101%  
Bromofluorobenzene 105%

QC Limits

(85-114)  
(90-110)  
(86-112)

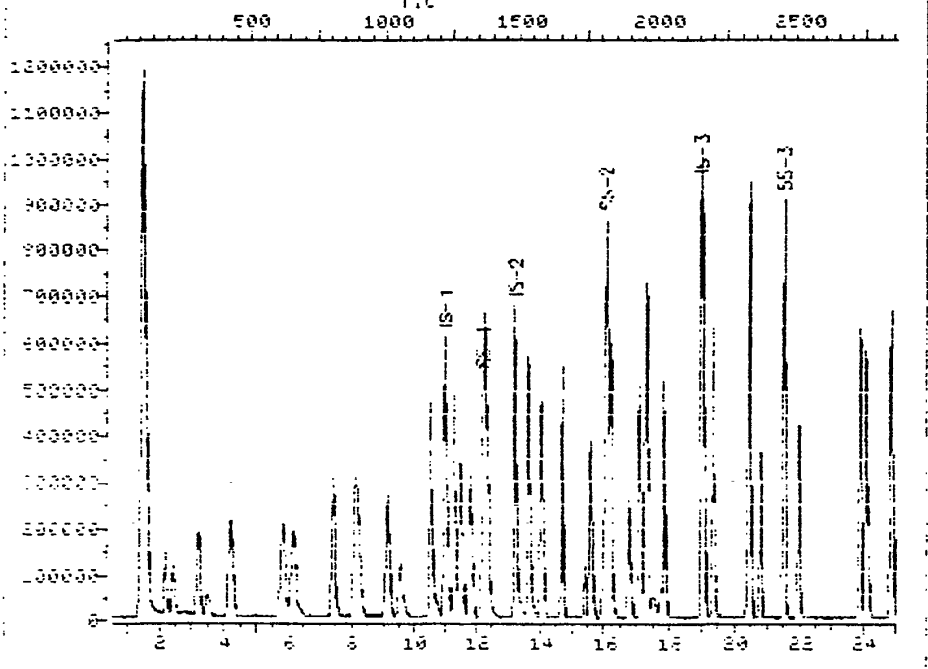
QUALIFIERS:

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NA = Not applicable or not available.

Analyst

Approved

1e 1.65520 36.0-252.0 amu. 624 REF 1 ;11P5;W;0;1;W;0;08 24793



Date Time: 2008-09-20 11:14:39  
 User: 31143371  
 Host: 31143371:10.10.10.10:2103:0

Client Output File: 14929:01  
Instrument ID: 14929

44 File: 10103:10T  
45 File: 10 FILE POP 40158:10T400 60-  
46 Laboratory: 90013:11:17

Last Call Time: none.

[illegible]

008529

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EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Semivolatile Analysis Data Report  
Page 1

008530

Client Sample Number : 46836  
Lab Sample Number : X74795  
Date Sampled : 08/06/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23391  
Method Blank No. : WB081193

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
bis(2-Chloroethyl) Ether	111-44-4	U	1.0
1,3-Dichlorobenzene	541-73-1	U	0.5
1,4-Dichlorobenzene	106-46-7	U	0.5
1,2-Dichlorobenzene	95-50-1	U	0.5
bis(2-chloroisopropyl) Ether	108-60-1	U	1.0
N-Nitroso-Di-n-Propylamine	621-64-7	U	1.0
Hexachloroethane	67-72-1	U	0.5
Nitrobenzene	98-95-3	U	1.0
Isophorone	78-59-1	U	1.0
bis(2-Chloroethoxy) Methane	111-91-1	U	1.0
1,2,4-Trichlorobenzene	120-82-1	U	0.5
Naphthalene	91-20-3	U	0.5
4-Chloroaniline	106-47-8	U	2.0
Hexachlorobutadiene	87-68-3	U	0.5
2-Methylnaphthalene	91-57-6	U	0.5
Hexachlorocyclopentadiene	77-47-4	U	2.0
2-Chloronaphthalene	91-58-7	U	2.0
2-Nitroaniline	88-74-4	U	2.0
Dimethylphthalate	131-11-3	U	0.5
2,6-Dinitrotoluene	606-20-2	U	2.0
acenaphthylene	208-96-8	U	0.5
-Nitroaniline	99-09-2	U	2.0
acenaphthene	83-32-9	U	0.5
Dibenzofuran	132-64-9	U	0.5
2,4-Dinitrotoluene	121-14-2	U	2.0
Diethylphthalate	84-66-2	U	0.5
4-Chlorophenyl-phenylether	7005-72-3	U	0.5
Fluorene	86-73-7	U	0.5
4-Nitroaniline	100-01-6	U	2.0
N-Nitrosodiphenylamine	86-30-6	U	0.5
4-Bromophenyl-phenylether	101-55-3	U	0.5
Hexachlorobenzene	118-74-1	U	0.5
Phenanthrene	85-01-8	U	0.5
Anthracene	120-12-7	U	0.5
Di-n-Butylphthalate	84-74-2	1	0.5
Fluoranthene	206-44-0	U	0.5
Pyrene	129-00-0	U	0.5
Butylbenzylphthalate	85-68-7	U	0.5
3,3'-Dichlorobenzidine	91-94-1	U	2.0
Benzo(a)Anthracene	56-55-3	U	0.5
bis(2-Ethylhexyl) Phthalate	117-81-7	1	0.5
Chrysene	218-01-9	U	0.5
Di-n-Octyl Phthalate	117-84-0	U	0.5
Benzo(b) Fluoranthene	205-99-2	U	0.5
Benzo(k) Fluoranthene	207-08-9	U	0.5
Benzo(a) Pyrene	50-32-8	U	0.5
Indeno(1,2,3-cd) Pyrene	193-39-5	U	0.5
Dibenz(a,h) Anthracene	53-70-3	U	0.5
Benzo(g,h,i) Perylene	191-24-2	U	0.5

Analyst

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EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Semivolatile Analysis Data Report  
Page 2

008531

Client Sample Number	: 46836	Client I.D.	: 8068
Lab Sample Number	: X74795	Lab Project No.	: 93-2741
Date Sampled	: 08/06/93	Effective Dilution	: 1.00
Date Received	: 08/07/93	Method	: 625
Date Extracted/Prepared	: 08/11/93	Matrix	: WATER
Date Analyzed	: 08/16/93	Lab File No.	: >23391
		Method Blank No.	: WB081193

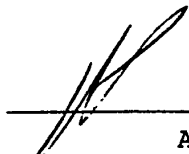
ACIDS

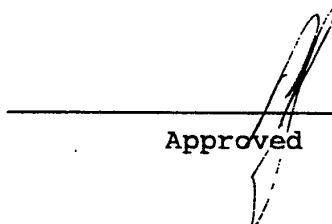
Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Phenol	108-95-2	U	2.0
2-Chlorophenol	95-57-8	U	2.0
Benzylalcohol	100-51-6	U	5.0
2-Methylphenol	95-48-7	U	1.0
4-Methylphenol	106-44-5	U	1.0
2-Nitrophenol	88-75-5	U	2.0
2,4-Dimethylphenol	105-67-9	U	2.0
Benzoic Acid	65-85-0	U	5.0
2,4-Dichlorophenol	120-83-2	U	2.0
4-Chloro-3-Methylphenol	59-50-7	U	2.0
2,4,6-Trichlorophenol	88-06-2	U	2.0
2,4-Dinitrophenol	51-28-5	U	10.0
4-Nitrophenol	100-02-7	U	5.0
4,6-Dinitro-2-Methylphenol	534-52-1	U	10.0
Pentachlorophenol	87-86-5	U	5.0
2,4,5-Trichlorophenol	95-95-4	U	2.0

Expected Surrogate Recoveries:	Actual Recoveries:	QC Limits
Nitrobenzene-d5	100 ug/L	88% (35-113)
2-Fluorobiphenyl	100 ug/L	86% (45-116)
Terphenyl-d14	100 ug/L	56% (33- 95)
Phenol-d6	200 ug/L	45% (40- 94)
2-Fluorophenol	200 ug/L	64% (35-100)
2,4,6 Tribromophenol	200 ug/L	34% (30-123)

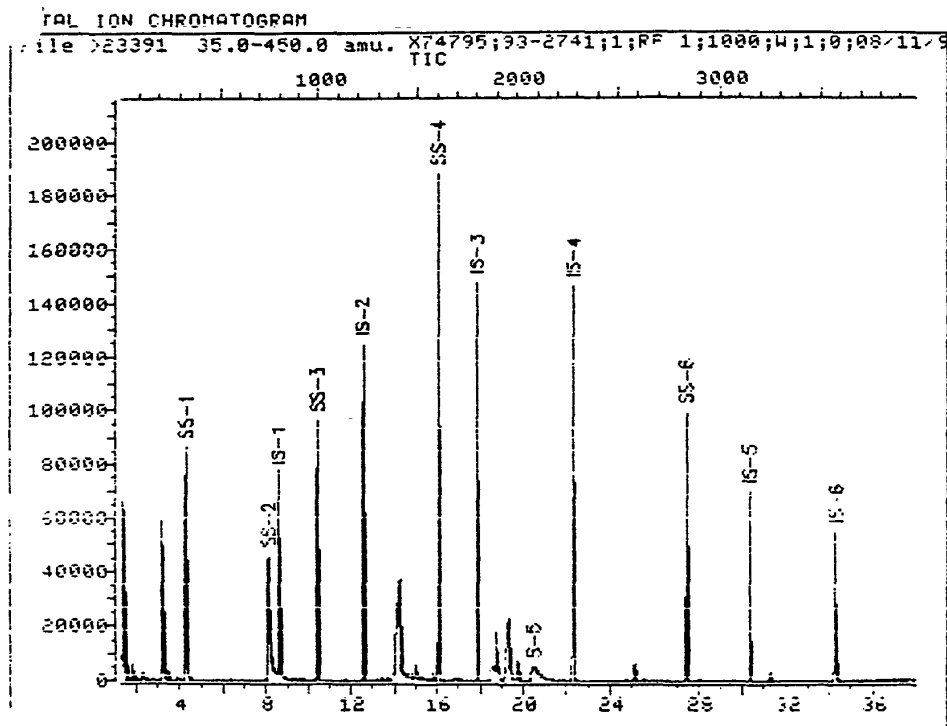
QUALIFIERS:

U = Compound analyzed for, but not detected above the reporting limits.  
 B = Compound found in blank and sample. Compare blank and sample data.  
 \* = Reporting limits are roughly the method detection limits for reagent water.  
 E = Compound is detected but concentration is outside of calibration limits.  
 Unless otherwise noted concentrations for soils are reported on a dry weight basis. (NA = not applicable or not available)

  
\_\_\_\_\_  
Analyst

  
\_\_\_\_\_  
Approved

008532



Data File: >23391::B2 Quant Output File: >23391::C2  
 Name: X74795;93-2741;1;PP Instrument ID: BNA 1  
 Misc: 1;1000;W;1;0;08/11/93;W;1 BTL#55

Id File: ID 827::QT  
 Title: SEMI-VOLATILE PRIORITY POLLUTANT IDENTIFICATION METHOD 8270  
 Last Calibration: 930816 15:34 Last Cal Time: none

Operator ID: BOB  
 Quant Time: 930816 15:46  
 Injected at: 930816 15:07

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

Semivolatiles Analysis Data Report  
Page 1

Client Sample Number : 2136-64  
Lab Sample Number : X74796  
Date Sampled : 08/07/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23392  
Method Blank No. : WB081193

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
bis(2-Chloroethyl) Ether	111-44-4	U	1.0
1,3-Dichlorobenzene	541-73-1	U	0.5
1,4-Dichlorobenzene	106-46-7	U	0.5
1,2-Dichlorobenzene	95-50-1	U	0.5
bis(2-chloroisopropyl) Ether	108-60-1	U	1.0
N-Nitroso-Di-n-Propylamine	621-64-7	U	1.0
Hexachloroethane	67-72-1	U	0.5
Nitrobenzene	98-95-3	U	1.0
Isophorone	78-59-1	U	1.0
bis(2-Chloroethoxy) Methane	111-91-1	U	1.0
1,2,4-Trichlorobenzene	120-82-1	U	0.5
Naphthalene	91-20-3	U	0.5
4-Chloroaniline	106-47-8	U	2.0
Hexachlorobutadiene	87-68-3	U	0.5
2-Methylnaphthalene	91-57-6	U	0.5
Hexachlorocyclopentadiene	77-47-4	U	2.0
2-Chloronaphthalene	91-58-7	U	0.5
2-Nitroaniline	88-74-4	U	2.0
Dimethylphthalate	131-11-3	U	0.5
2,6-Dinitrotoluene	606-20-2	U	2.0
1-naphthylene	208-96-8	U	0.5
Nitroaniline	99-09-2	U	2.0
Acenaphthene	83-32-9	U	0.5
Dibenzofuran	132-64-9	U	0.5
2,4-Dinitrotoluene	121-14-2	U	2.0
Diethylphthalate	84-66-2	U	0.5
4-Chlorophenyl-phenylether	7005-72-3	U	0.5
Fluorene	86-73-7	U	0.5
4-Nitroaniline	100-01-6	U	2.0
N-Nitrosodiphenylamine	86-30-6	U	0.5
4-Bromophenyl-phenylether	101-55-3	U	0.5
Hexachlorobenzene	118-74-1	U	0.5
Phenanthrene	85-01-8	U	0.5
Anthracene	120-12-7	U	0.5
Di-n-Butylphthalate	84-74-2	8	0.5
Fluoranthene	206-44-0	U	0.5
Pyrene	129-00-0	U	0.5
Butylbenzylphthalate	85-68-7	7	0.5
3,3'-Dichlorobenzidine	91-94-1	U	2.0
Benzo(a)Anthracene	56-55-3	U	0.5
bis(2-Ethylhexyl) Phthalate	117-81-7	1	0.5
Chrysene	218-01-9	U	0.5
Di-n-Octyl Phthalate	117-84-0	U	0.5
Benzo(b) Fluoranthene	205-99-2	U	0.5
Benzo(k) Fluoranthene	207-08-9	U	0.5
Benzo(a) Pyrene	50-32-8	U	0.5
Indeno(1,2,3-cd) Pyrene	193-39-5	U	0.5
Dibenz(a,h) Anthracene	53-70-3	U	0.5
Benzo(g,h,i) Perylene	191-24-2	U	0.5

Analyst

Approved

008533

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Semivolatile Analysis Data Report  
Page 2

Client Sample Number : 2136-64  
Lab Sample Number : X74796  
Date Sampled : 08/07/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23392  
Method Blank No. : WB081193

008534

ACIDS

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Phenol	108-95-2	U	2.0
2-Chlorophenol	95-57-8	U	2.0
Benzylalcohol	100-51-6	U	5.0
2-Methylphenol	95-48-7	U	1.0
4-Methylphenol	106-44-5	U	1.0
2-Nitrophenol	88-75-5	U	2.0
2,4-Dimethylphenol	105-67-9	U	2.0
Benzoic Acid	65-85-0	U	5.0
2,4-Dichlorophenol	120-83-2	U	2.0
4-Chloro-3-Methylphenol	59-50-7	U	2.0
2,4,6-Trichlorophenol	88-06-2	U	2.0
2,4-Dinitrophenol	51-28-5	U	10.0
4-Nitrophenol	100-02-7	U	5.0
4,6-Dinitro-2-Methylphenol	534-52-1	U	10.0
Pentachlorophenol	87-86-5	U	5.0
2,4,5-Trichlorophenol	95-95-4	U	2.0

Expected Surrogate Recoveries:

Nitrobenzene-d5 100  
2-Fluorobiphenyl 100  
Terphenyl-d14 100  
Phenol-d6 200  
2-Fluorophenol 200  
2,4,6 Tribromophenol 200

Actual Recoveries:

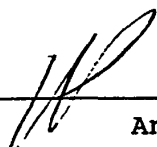
ug/L  
ug/L  
ug/L  
ug/L  
ug/L  
ug/L


QC Limits

88% (35-113)  
87% (45-116)  
80% (33- 95)  
6% X (40- 94)  
1% X (35-100)  
1% X (30-123)

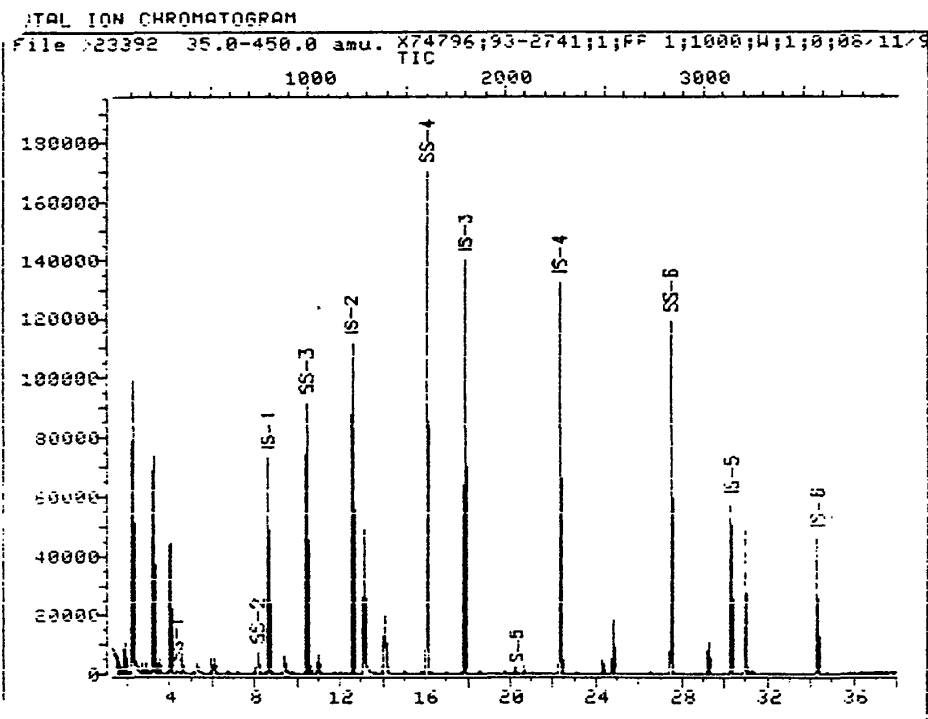
QUALIFIERS:

X = Poor surrogate recovery exhibited in duplicate indicating matrix effect.  
U = Compound analyzed for, but not detected above the reporting limits.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
Unless otherwise noted concentrations for soils are reported on a dry weight basis. (NA = not applicable or not available)

  
\_\_\_\_\_  
Analyst

  
\_\_\_\_\_  
Approved

008535



Data File: >23392::02 Quant Output File: >23392::02  
 Name: X74796;93-2741;1;PP Instrument ID: BNA 1  
 Misc: 1;1000;W;1;0;08/11/93;W;1 BTL#56

Id File: ID 827::0T  
 Title: SEMI-VOLATILE PRIORITY POLLUTANT IDENTIFICATION METHOD 8270  
 Last Calibration: 930816 15:34 Last Cal Time: <none>

Operator ID: 606  
 Quant Time: 930816 16:33  
 Injected at: 930816 16:54

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021  
Method Blank Report  
Semivolatile Analysis Data Report  
Page 1

008536

Lab Sample Number : WB081193  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23400

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
bis(2-Chloroethyl) Ether	111-44-4	U	1.0
1,3-Dichlorobenzene	541-73-1	U	0.5
1,4-Dichlorobenzene	106-46-7	U	0.5
1,2-Dichlorobenzene	95-50-1	U	0.5
bis(2-chloroisopropyl) Ether	108-60-1	U	1.0
N-Nitroso-Di-n-Propylamine	621-64-7	U	1.0
Hexachloroethane	67-72-1	U	0.5
Nitrobenzene	98-95-3	U	1.0
Isophorone	78-59-1	U	1.0
bis(2-Chloroethoxy) Methane	111-91-1	U	1.0
1,2,4-Trichlorobenzene	120-82-1	U	0.5
Naphthalene	91-20-3	U	0.5
4-Chloroaniline	106-47-8	U	2.0
Hexachlorobutadiene	87-68-3	U	0.5
2-Methylnaphthalene	91-57-6	U	0.5
Hexachlorocyclopentadiene	77-47-4	U	2.0
2-Chloronaphthalene	91-58-7	U	0.5
2-Nitroaniline	88-74-4	U	2.0
Dimethylphthalate	131-11-3	U	0.5
2,6-Dinitrotoluene	606-20-2	U	2.0
Benaphthylene	208-96-8	U	0.5
-Nitroaniline	99-09-2	U	2.0
Acenaphthene	83-32-9	U	0.5
Dibenzofuran	132-64-9	U	0.5
2,4-Dinitrotoluene	121-14-2	U	2.0
Diethylphthalate	84-66-2	U	0.5
4-Chlorophenyl-phenylether	7005-72-3	U	0.5
Fluorene	86-73-7	U	0.5
4-Nitroaniline	100-01-6	U	2.0
N-Nitrosodiphenylamine	86-30-6	U	0.5
4-Bromophenyl-phenylether	101-55-3	U	0.5
Hexachlorobenzene	118-74-1	U	0.5
Phenanthrene	85-01-8	U	0.5
Anthracene	120-12-7	U	0.5
Di-n-Butylphthalate	84-74-2	U	0.5
Fluoranthene	206-44-0	U	0.5
Pyrene	129-00-0	U	0.5
Butylbenzylphthalate	85-68-7	U	0.5
3,3'-Dichlorobenzidine	91-94-1	U	2.0
Benzo(a)Anthracene	56-55-3	U	0.5
bis(2-Ethylhexyl) Phthalate	117-81-7	1	0.5
Chrysene	218-01-9	U	0.5
Di-n-Octyl Phthalate	117-84-0	U	0.5
Benzo(b) Fluoranthene	205-99-2	U	0.5
Benzo(k) Fluoranthene	207-08-9	U	0.5
Benzo(a) Pyrene	50-32-8	U	0.5
Indeno(1,2,3-cd) Pyrene	193-39-5	U	0.5
Dibenz(a,h) Anthracene	53-70-3	U	0.5
Benzo(g,h,i) Perylene	191-24-2	U	0.5

Analyst

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(303)425-6021  
Method Blank Report  
Semivolatile Analysis Data Report  
Page 2

008537

Lab Sample Number : WB081193  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23400  
Method Blank No. : WB081193

ACIDS

Compound Name	Cas Number	Conc. ug/L	Reporting Limit* ug/L
Phenol	108-95-2	U	2.0
2-Chlorophenol	95-57-8	U	2.0
Benzylalcohol	100-51-6	U	5.0
2-Methylphenol	95-48-7	U	1.0
4-Methylphenol	106-44-5	U	1.0
2-Nitrophenol	88-75-5	U	2.0
2,4-Dimethylphenol	105-67-9	U	2.0
Benzoic Acid	65-85-0	U	5.0
2,4-Dichlorophenol	120-83-2	U	2.0
4-Chloro-3-Methylphenol	59-50-7	U	2.0
2,4,6-Trichlorophenol	88-06-2	U	2.0
2,4-Dinitrophenol	51-28-5	U	10.0
4-Nitrophenol	100-02-7	U	5.0
4,6-Dinitro-2-Methylphenol	534-52-1	U	10.0
Pentachlorophenol	87-86-5	U	5.0
2,4,5-Trichlorophenol	95-95-4	U	2.0

Expected Surrogate Recoveries:

Nitrobenzene-d5	100
2-Fluorobiphenyl	100
Terphenyl-d14	100
Phenol-d6	200
2-Fluorophenol	200
2,4,6 Tribromophenol	200

Actual Recoveries:

ug/L	90%	QC Limits
ug/L	93%	(35-113)
ug/L	82%	(45-116)
ug/L	84%	(33- 95)
ug/L	77%	(40- 94)
ug/L	59%	(35-100)
ug/L		(30-123)

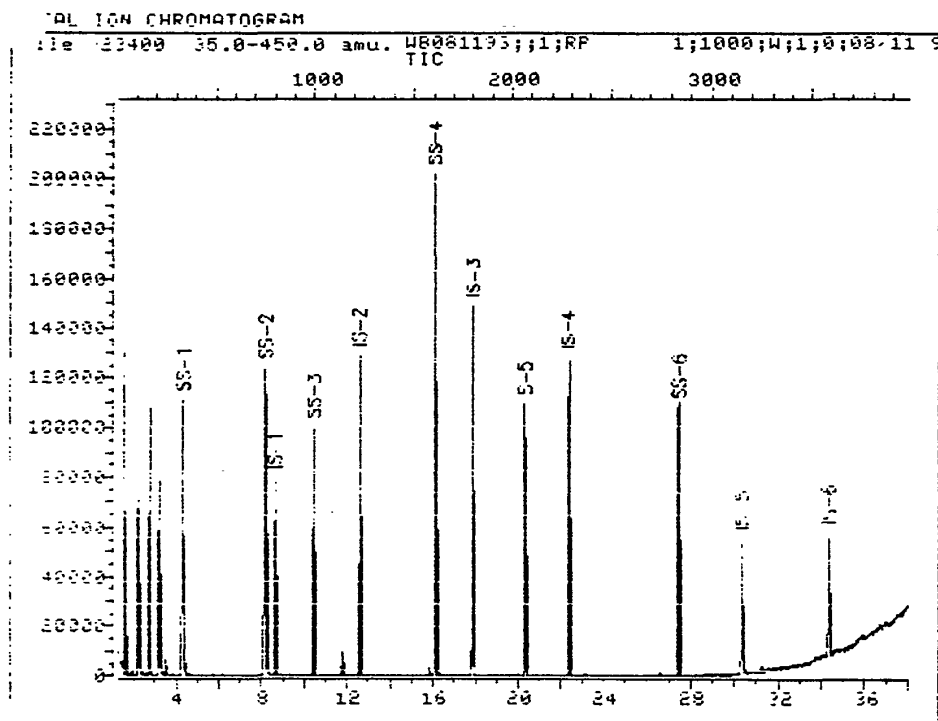
QUALIFIERS:

U = Compound analyzed for, but not detected above the reporting limits.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water  
E = Compound is detected but concentration is outside of calibration limits.  
Unless otherwise noted concentrations for soils are reported on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved

008538



Data File: 23400::82

Quant Output File: 23400::01

Name: WB081193;;1;PP

Instrument ID: BNA 1

Asc: 1;1000;W;1;0;08-11/93;W;1

ETL#4

In File: 10-827::01

Title: SEMI-VOLATILE PRIORITY POLLUTANT IDENTIFICATION METHOD 8070

Last Calibration: 930816 15:34

Last Cal Time: none

Operator ID: 8008

Acq Time: 930817 07:50

Injected at: 930816 22:06



EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Semivolatiles Analysis Data Report  
Page 1

008539

Client Sample Number : 2136-64 REF  
Lab Sample Number : X74796REF  
Date Sampled : 08/07/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23399  
Method Blank No. : WB081193

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	REC %
bis(2-Chloroethyl) Ether	111-44-4	92	92%
1,3-Dichlorobenzene	541-73-1	49	49%
1,4-Dichlorobenzene	106-46-7	52	52%
1,2-Dichlorobenzene	95-50-1	56	56%
bis(2-chloroisopropyl) Ether	108-60-1	50	50%
N-Nitroso-Di-n-Propylamine	621-64-7	99	99%
Hexachloroethane	67-72-1	44	44%
Nitrobenzene	98-95-3	73	73%
Isophorone	78-59-1	68	68%
bis(2-Chloroethoxy) Methane	111-91-1	100	100%
1,2,4-Trichlorobenzene	120-82-1	63	63%
Naphthalene	91-20-3	83	83%
4-Chloroaniline	106-47-8	NS	---
Hexachlorobutadiene	87-68-3	58	58%
2-Methylnaphthalene	91-57-6	NS	---
Hexachlorocyclopentadiene	77-47-4	27	27%
2-Chloronaphthalene	91-58-7	72	72%
2-Nitroaniline	88-74-4	NS	---
Dimethylphthalate	131-11-3	25	25%
2,6-Dinitrotoluene	606-20-2	76	76%
Acenaphthylene	208-96-8	90	90%
-Nitroaniline	99-09-2	NS	---
Acenaphthene	83-32-9	95	95%
Dibenzofuran	132-64-9	NS	---
2,4-Dinitrotoluene	121-14-2	77	77%
Diethylphthalate	84-66-2	56	56%
4-Chlorophenyl-phenylether	7005-72-3	99	99%
Fluorene	86-73-7	86	86%
4-Nitroaniline	100-01-6	NS	---
N-Nitrosodiphenylamine	86-30-6	100	100%
4-Bromophenyl-phenylether	101-55-3	110	110%
Hexachlorobenzene	118-74-1	82	82%
Phenanthrene	85-01-8	91	91%
Anthracene	120-12-7	93	93%
Di-n-Butylphthalate	84-74-2	100	100%
Fluoranthene	206-44-0	81	81%
Pyrene	129-00-0	78	78%
Butylbenzylphthalate	85-68-7	99	99%
3,3'-Dichlorobenzidine	91-94-1	65	65%
Benzo(a) Anthracene	56-55-3	91	91%
bis(2-Ethylhexyl) Phthalate	117-81-7	100	100%
Chrysene	218-01-9	96	96%
Di-n-Octyl Phthalate	117-84-0	93	93%
Benzo(b) Fluoranthene	205-99-2	92	92%
Benzo(k) Fluoranthene	207-08-9	78	78%
Benzo(a) Pyrene	50-32-8	92	92%
Indeno(1,2,3-cd) Pyrene	193-39-5	89	89%
Dibenz(a,h) Anthracene	53-70-3	100	100%
Benzo(g,h,i) Perylene	191-24-2	92	92%

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303) 425-6021

Semivolatiles Analysis Data Report  
Page 2

Client Sample Number : 2136-64 REF  
Lab Sample Number : X74796REF  
Date Sampled : 08/07/93  
Date Received : 08/07/93  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23399  
Method Blank No. : WB081193

008540

ACIDS

Compound Name	Cas Number	Conc. ug/L	REC %
Phenol	108-95-2	4	4%
2-Chlorophenol	95-57-8	3	3%
Benzylalcohol	100-51-6	NS	---
2-Methylphenol	95-48-7	NS	---
4-Methylphenol	106-44-5	NS	---
2-Nitrophenol	88-75-5	9	9%
2,4-Dimethylphenol	105-67-9	27	27%
Benzoic Acid	65-85-0	NS	---
2,4-Dichlorophenol	120-83-2	3	3%
4-Chloro-3-Methylphenol	59-50-7	14	14%
2,4,6-Trichlorophenol	88-06-2	NS	---
2,4-Dinitrophenol	51-28-5	11	11%
4-Nitrophenol	100-02-7	10	10%
4,6-Dinitro-2-Methylphenol	534-52-1	26	26%
Pentachlorophenol	87-86-5	5	5%
2,4,5-Trichlorophenol	95-95-4	NS	---

Expected Surrogate Recoveries:

Nitrobenzene-d5	100
2-Fluorobiphenyl	100
Terphenyl-d14	100
Phenol-d6	200
2-Fluorophenol	200
2,4,6 Tribromophenol	200

Actual Recoveries:

ug/L	85%	(35-113)
ug/L	84%	(45-116)
ug/L	63%	(33- 95)
ug/L	6% X	(40- 94)
ug/L	1% X	(35-100)
ug/L	2% X	(30-123)

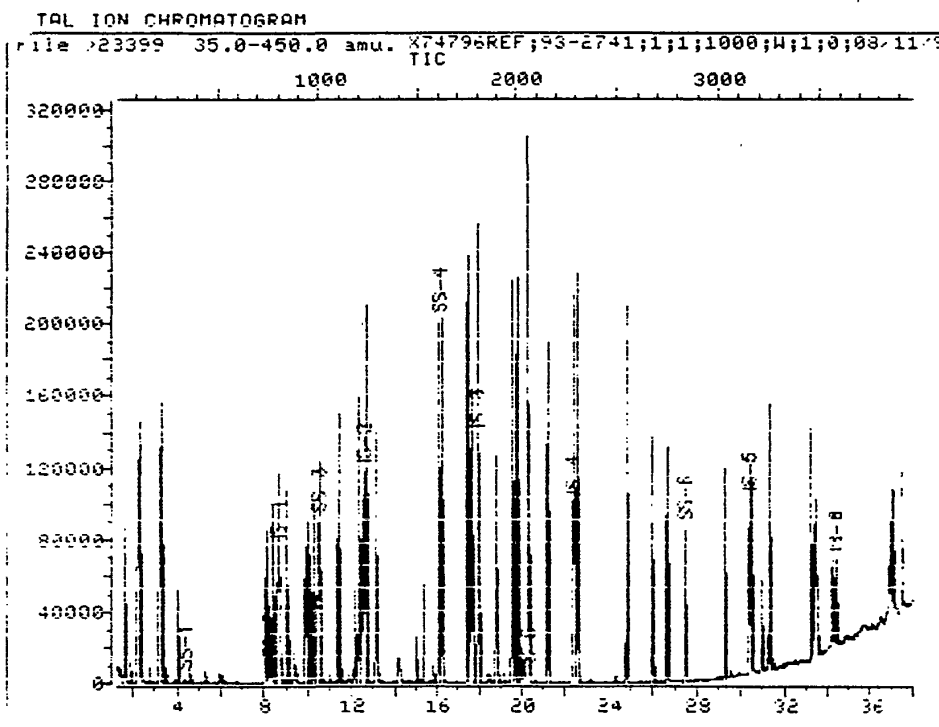
QC Limits

QUALIFIERS:

X = Poor surrogate recovery exhibited in duplicate indicating matrix effect.  
U = Compound analyzed for, but not detected above the reporting limits.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water  
E = Compound is detected but concentration is outside of calibration limits.  
Unless otherwise noted concentrations for soils are reported on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved



Data File: 23399::E1 Quant Output File: 23399::Q1  
 Name: X74796REF;93-2741;1; Instrument ID: BNA 1  
 Misc: 1:1000;W;1;0;08-11-93;0;1 ETL#:3  
 Id File: ID\_927::QT  
 Title: SEMI-VOLATILE AIRCRAFT POLLUTANT IDENTIFICATION METHOD 9270  
 Last Calibration: 930816 15:34 Last Deal Time: <none>  
 Operator ID: BCB  
 Quant Time: 930817 07:47  
 Injected at: 930816 21:20

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Semivolatiles Analysis Data Report  
Page 1

008542

Client Sample Number : DI REF  
Lab Sample Number : DI REF  
Date Sampled : NA  
Date Received : NA  
Date Extracted/Prepared : 08/11/93  
Date Analyzed : 08/16/93

Client I.D. : 8068  
Lab Project No. : 93-2741  
Effective Dilution : 1.00  
Method : 625  
Matrix : WATER  
Lab File No. : >23401  
Method Blank No. : WB081193

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	REC %
bis(2-Chloroethyl) Ether	111-44-4	98	98%
1,3-Dichlorobenzene	541-73-1	66	66%
1,4-Dichlorobenzene	106-46-7	68	68%
1,2-Dichlorobenzene	95-50-1	70	70%
bis(2-chloroisopropyl) Ether	108-60-1	110	110%
N-Nitroso-Di-n-Propylamine	621-64-7	110	110%
Hexachloroethane	67-72-1	64	64%
Nitrobenzene	98-95-3	85	85%
Isophorone	78-59-1	80	80%
bis(2-Chloroethoxy) Methane	111-91-1	120	120%
1,2,4-Trichlorobenzene	120-82-1	80	80%
Naphthalene	91-20-3	100	100%
4-Chloroaniline	106-47-8	NS	---
Hexachlorobutadiene	87-68-3	77	77%
2-Methylnaphthalene	91-57-6	NS	---
Hexachlorocyclopentadiene	77-47-4	8	8%
2-Chloronaphthalene	91-58-7	84	84%
2-Nitroaniline	88-74-4	NS	---
Dimethylphthalate	131-11-3	23	23%
2,6-Dinitrotoluene	606-20-2	88	88%
acenaphthylene	208-96-8	100	100%
Nitroaniline	99-09-2	NS	---
acenaphthene	83-32-9	110	110%
Dibenzofuran	132-64-9	NS	---
2,4-Dinitrotoluene	121-14-2	85	85%
Diethylphthalate	84-66-2	76	76%
4-Chlorophenyl-phenylether	7005-72-3	110	110%
Fluorene	86-73-7	98	98%
4-Nitroaniline	100-01-6	NS	---
N-Nitrosodiphenylamine	86-30-6	110	110%
4-Bromophenyl-phenylether	101-55-3	120	120%
Hexachlorobenzene	118-74-1	94	94%
Phenanthrene	85-01-8	100	100%
Anthracene	120-12-7	110	110%
Di-n-Butylphthalate	84-74-2	100	100%
Fluoranthene	206-44-0	86	86%
Pyrene	129-00-0	100	100%
Butylbenzylphthalate	85-68-7	110	110%
3,3'-Dichlorobenzidine	91-94-1	100	100%
Benzo(a)Anthracene	56-55-3	110	110%
bis(2-Ethylhexyl) Phthalate	117-81-7	120	120%
Chrysene	218-01-9	110	110%
Di-n-Octyl Phthalate	117-84-0	110	110%
Benzo(b)Fluoranthene	205-99-2	110	110%
Benzo(k)Fluoranthene	207-08-9	94	94%
Benzo(a)Pyrene	50-32-8	110	110%
Indeno(1,2,3-cd)Pyrene	193-39-5	100	100%
Dibenz(a,h)Anthracene	53-70-3	110	110%
Benzo(g,h,i)Perylene	191-24-2	110	110%

Analyst

Approved

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Semivolatiles Analysis Data Report  
Page 2

008543

Client Sample Number	: DI REF	Client I.D.	: 8068
Lab Sample Number	: DI REF	Lab Project No.	: 93-2741
Date Sampled	: NA	Effective Dilution	: 1.00
Date Received	: NA	Method	: 625
Date Extracted/Prepared	: 08/11/93	Matrix	: WATER
Date Analyzed	: 08/16/93	Lab File No.	: >23401
		Method Blank No.	: WB081193

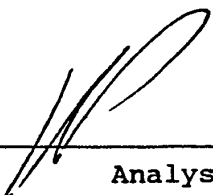
ACIDS


Compound Name	Cas Number	Conc. ug/L	REC %
Phenol	108-95-2	57	57%
2-Chlorophenol	95-57-8	57	57%
Benzylalcohol	100-51-6	U	---
2-Methylphenol	95-48-7	U	---
4-Methylphenol	106-44-5	U	---
2-Nitrophenol	88-75-5	62	62%
2,4-Dimethylphenol	105-67-9	44	44%
Benzoic Acid	65-85-0	U	---
2,4-Dichlorophenol	120-83-2	63	63%
4-Chloro-3-Methylphenol	59-50-7	59	59%
2,4,6-Trichlorophenol	88-06-2	61	---
2,4-Dinitrophenol	51-28-5	6	6%
4-Nitrophenol	100-02-7	27	27%
4,6-Dinitro-2-Methylphenol	534-52-1	28	28%
Pentachlorophenol	87-86-5	21	21%
2,4,5-Trichlorophenol	95-95-4	U	---

Expected Surrogate Recoveries:	Actual Recoveries:	QC Limits
Nitrobenzene-d5	100 ug/L	92% (35-113)
2-Fluorobiphenyl	100 ug/L	94% (45-116)
Terphenyl-d14	100 ug/L	87% (33-95)
Phenol-d6	200 ug/L	87% (40-94)
2-Fluorophenol	200 ug/L	80% (35-100)
2,4,6 Tribromophenol	200 ug/L	68% (30-123)

QUALIFIERS:

U = Compound analyzed for, but not detected above the reporting limits.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Reporting limits are roughly the method detection limits for reagent water.  
E = Compound is detected but concentration is outside of calibration limits.  
Unless otherwise noted concentrations for soils are reported on a dry weight basis. (NA = not applicable or not available)

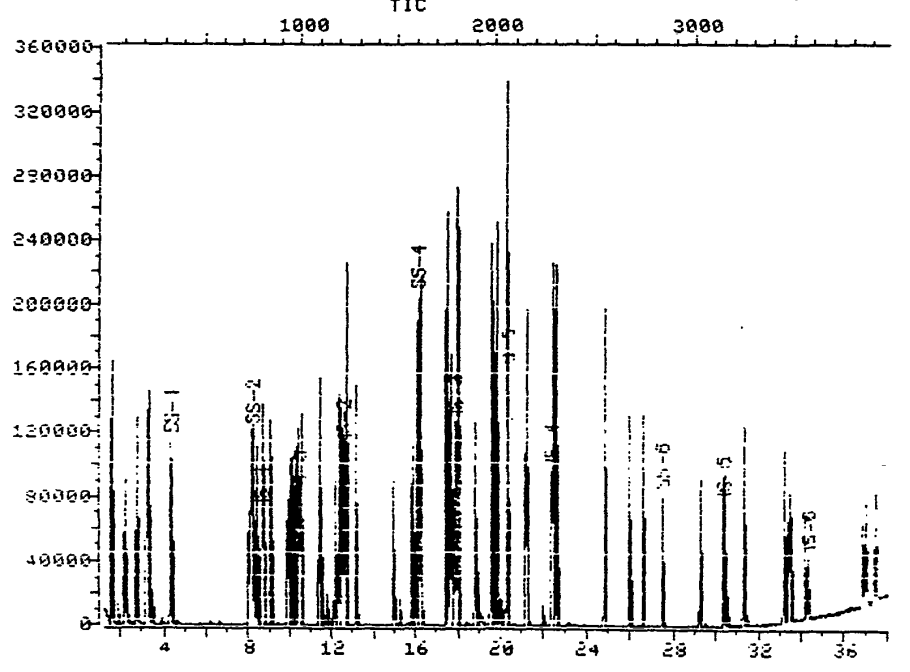
  
\_\_\_\_\_  
Analyst

  
\_\_\_\_\_  
Approved

008544

## TAL ION CHROMATOGRAM

File: 23401 35.0-450.0 amu. 01 REF ;;1;PP 1;1000;W;1;0;08/11/93



Data File: 23401::B2

Quant Output File: 23401::01

Name: 01 REF ;;1;PP

Instrument ID: BNA 1

Misc: 1;1000;W;1;0;08/11/93;U:1

BTL#08

Id File: ID 827::01

Title: SEMI-VOLATILE PRIORITY POLLUTANT IDENTIFICATION METHOD 8270

Last Calibration: 930816 15:34

Last Qcal Time: &lt;none&gt;

Operator ID: BOB

Quant Time: 930817 07:52

Injected at: 930816 22:53

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Pesticide & PCB Data Report

008545

Client Sample #	: 46836	Client Project #	: 8068
Lab Sample #	: X74795	Lab Project #	: 93-2741
Date Sampled	: 08/06/93	Dilution Factor	: 1.000
Date Received	: 08/07/93	Method	: 608
Date Extracted/Prepared	: 08/12/93	Matrix	: Water
Date Analyzed	: 08/13/93	Lab File No.	: ECD12887
Level	: LOW	Method Blank No.	: WB060793
pH	: 7		

Compound Name	Cas Number	Concentration ug/L	MDL* ug/L
alpha-BHC	319-84-6	U	0.003
beta-BHC	319-85-7	U	0.006
delta-BHC	319-86-8	U	0.009
gamma-BHC	58-89-9	U	0.004
Heptachlor	76-44-8	U	0.003
Aldrin	309-00-2	U	0.004
Heptachlor epoxide	1024-57-3	U	0.008
Endosulfan I	959-98-8	U	0.01
Dieldrin	60-57-1	U	0.002
4,4'-DDE	72-55-9	U	0.004
Endrin	72-20-8	U	0.006
Endosulfan II	33213-65-9	U	0.004
4,4'-DDD	72-54-8	U	0.01
Endosulfan sulfate	1031-07-8	U	0.007
4,4'-DDT	50-29-3	U	0.01
Methoxychlor	72-43-5	U	0.05
Endrin ketone	53494-70-5	U	0.01
alpha-Chlordane	5103-71-9	U	0.05
gamma-Chlordane	5103-74-2	U	0.05
Toxaphene	8001-35-2	U	0.24
Aroclor-1016	12674-11-2	U	0.05
Aroclor-1221	11104-28-2	U	0.05
Aroclor-1232	11141-16-5	U	0.05
Aroclor-1242	53469-21-9	U	0.07
Aroclor-1248	12672-29-6	U	0.05
Aroclor-1254	11097-69-1	U	0.1
Aroclor-1260	11096-82-5	U	0.1

Surrogate Recovery:

TCMX	95%	(QC Reporting Limits 53-112%)
DCB	49%	(QC Reporting Limits 34-106%)

QUALIFIERS:

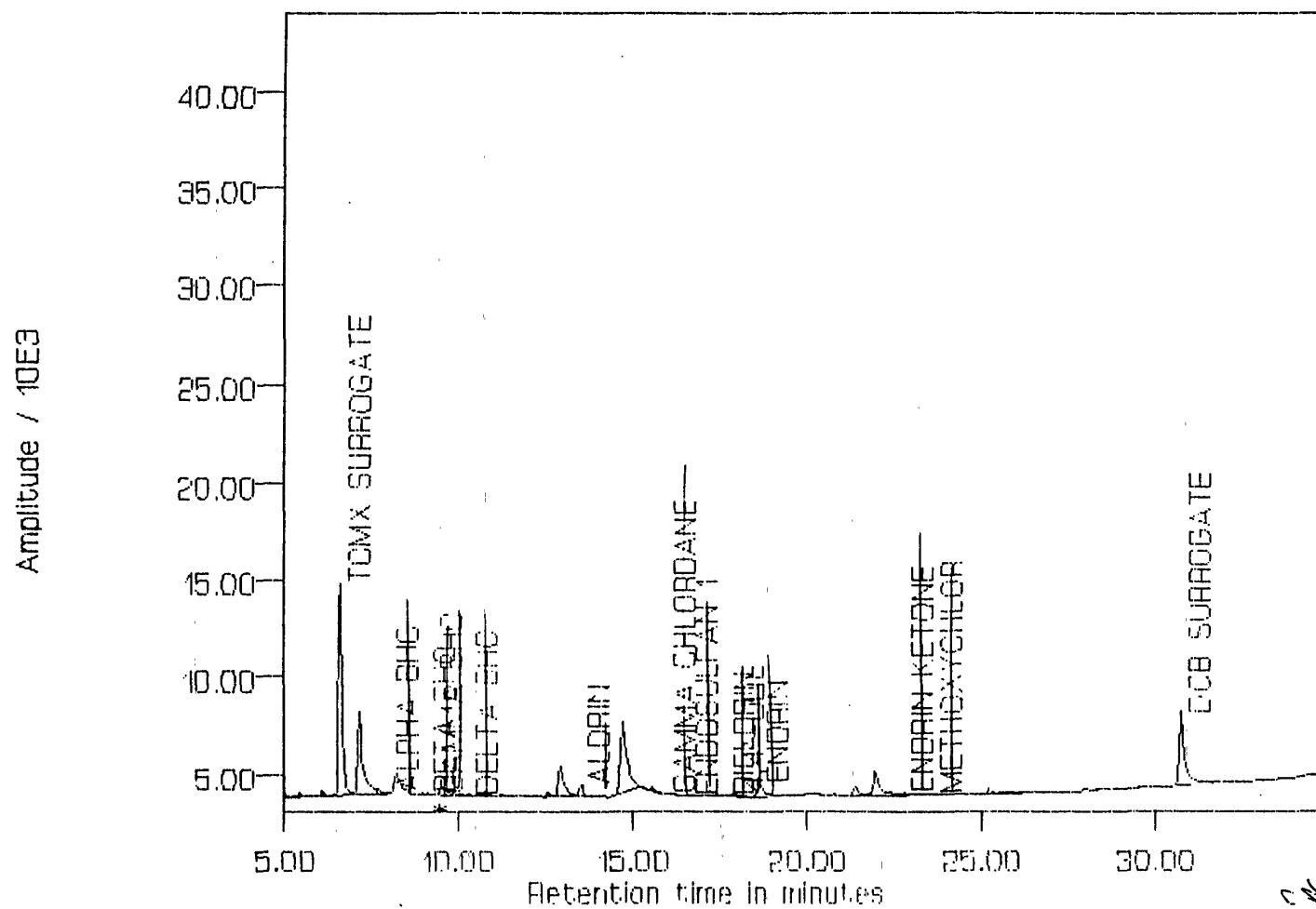
U = Compound analyzed for, but not detected.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Indicates the Method Detection (MDL). MDLs for Methoxychlor, Endrin ketone, alpha & gamma -Chlordane, and all PCBs except Aroclor-1242 equal one tenth the EPA CLP target quantitation limit.

J. Leonard  
Analyst

John W. Ryan  
Approved

008546

Sample : X74795 (Client#46836) Injected : FRI AUG 13, 1993 5:40:03 AM



Result : ECD13532

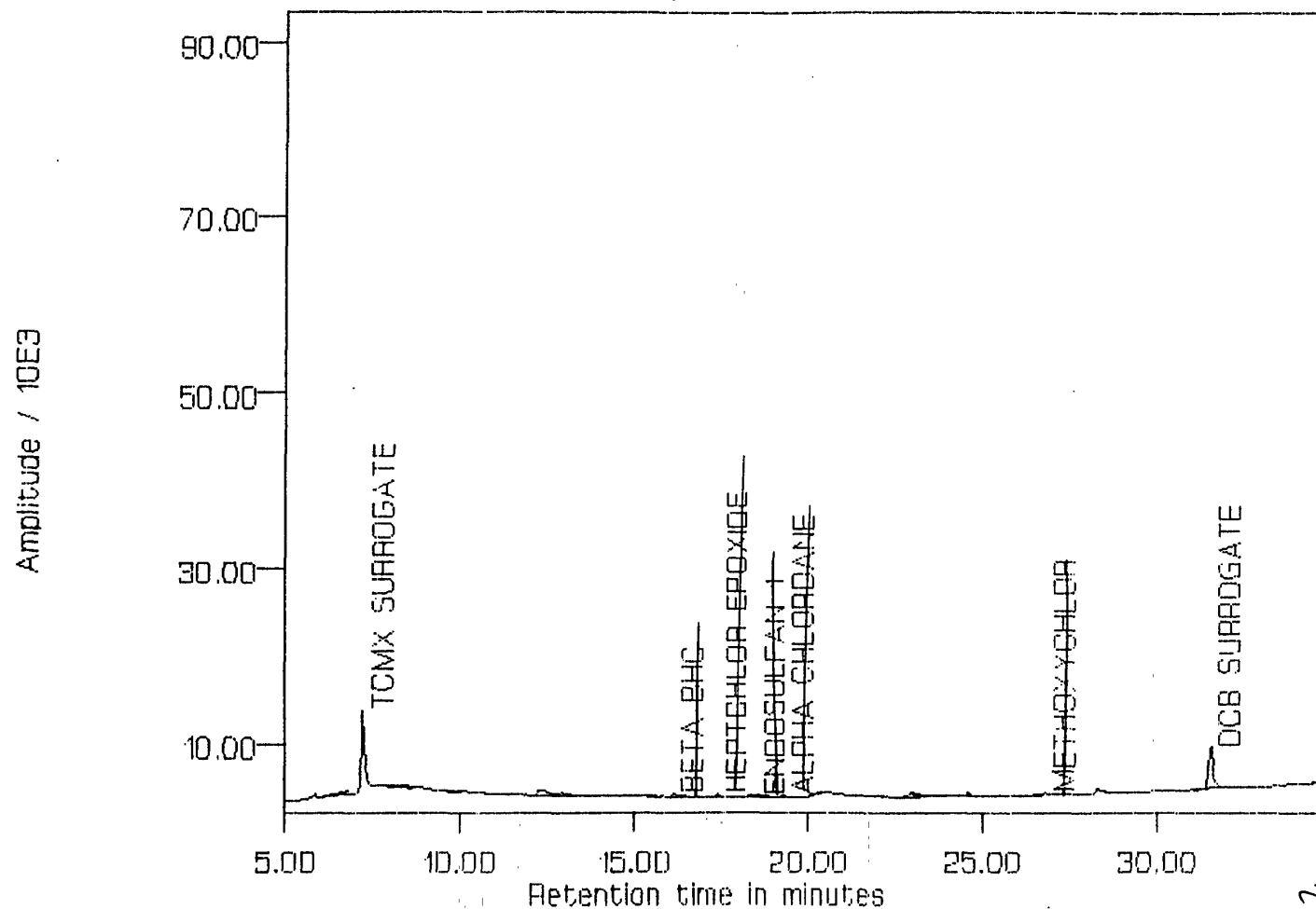
Method : PEST1AUG11

8/19/93 PC



008547

Sample : X74795 Injected : FRI AUG 13, 1993 5:40:03 AM



Result : ECD29532

Method : PEST2AUG11

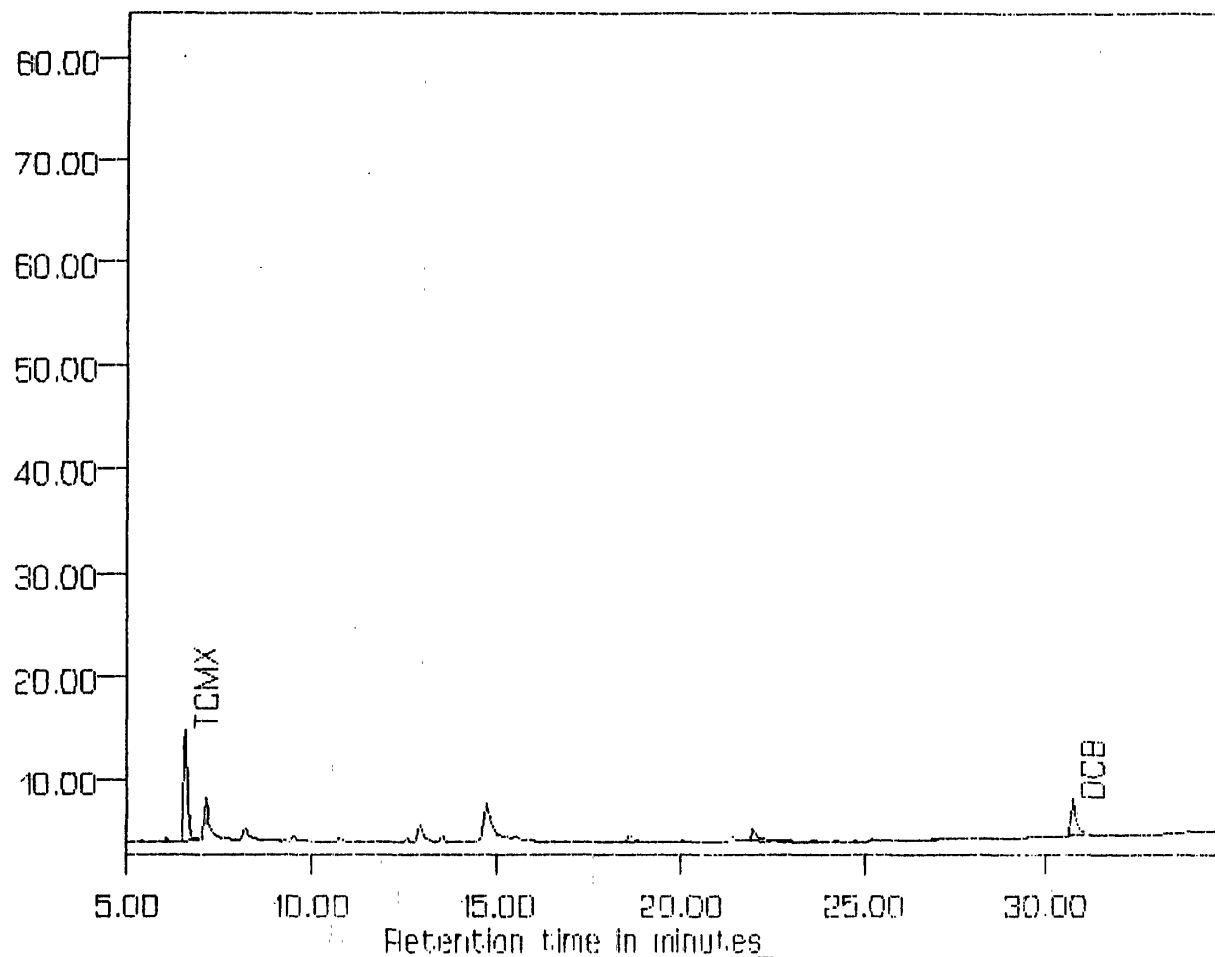
8/19/93 JK

845800

(PCB)

Sample : X74795 (Client#46836) Injected : FRI AUG 13, 1993 5:40:03 AM

Amplitude / 10E3



Result : ECC13532

Method : (AR1016)

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021

Pesticide & PCB Data Report

Client Sample #	: 2136-64	Client Project #	: 8068
Lab Sample #	: X74796	Lab Project #	: 93-2741
Date Sampled	: 08/07/93	Dilution Factor	: 1.000
Date Received	: 08/07/93	Method	: 608
Date Extracted/Prepared	: 08/12/93	Matrix	: Water
Date Analyzed	: 08/13/93	Lab File No.	: ECD12887
Level	: LOW	Method Blank No.	: WB060793
pH	: 7		

Compound Name	Cas Number	Concentration ug/L	MDL* ug/L
alpha-BHC	319-84-6	0.044	0.003
beta-BHC	319-85-7	U	0.006
delta-BHC	319-86-8	U	0.009
gamma-BHC	58-89-9	U	0.004
Heptachlor	76-44-8	U	0.003
Aldrin	309-00-2	U	0.004
Heptachlor epoxide	1024-57-3	U	0.008
Endosulfan I	959-98-8	U	0.01
Dieldrin	60-57-1	U	0.002
4,4'DDE	72-55-9	U	0.004
drin	72-20-8	U	0.006
Endosulfan II	33213-65-9	U	0.004
4,4'-DDD	72-54-8	U	0.01
Endosulfan sulfate	1031-07-8	U	0.007
4,4'-DDT	50-29-3	U	0.01
Methoxychlor	72-43-5	U	0.05
Endrin ketone	53494-70-5	U	0.01
alpha-Chlordane	5103-71-9	U	0.05
gamma-Chlordane	5103-74-2	U	0.05
Toxaphene	8001-35-2	U	0.24
Aroclor-1016	12674-11-2	U	0.05
Aroclor-1221	11104-28-2	U	0.05
Aroclor-1232	11141-16-5	U	0.05
Aroclor-1242	53469-21-9	U	0.07
Aroclor-1248	12672-29-6	U	0.05
Aroclor-1254	11097-69-1	U	0.1
Aroclor-1260	11096-82-5	U	0.1

Surrogate Recovery:

TCMX	129%	(QC Reporting Limits 53-112%)
DCB	99%	(QC Reporting Limits 34-106%)

QUALIFIERS:

U = Compound analyzed for, but not detected.  
B = Compound found in blank and sample. Compare blank and sample data.  
\* = Indicates the Method Detection (MDL). MDLs for Methoxychlor, Endrin ketone, alpha & gamma -Chlordane, and all PCBs except Aroclor-1242 equal one tenth the EPA CLP target quantitation limit.

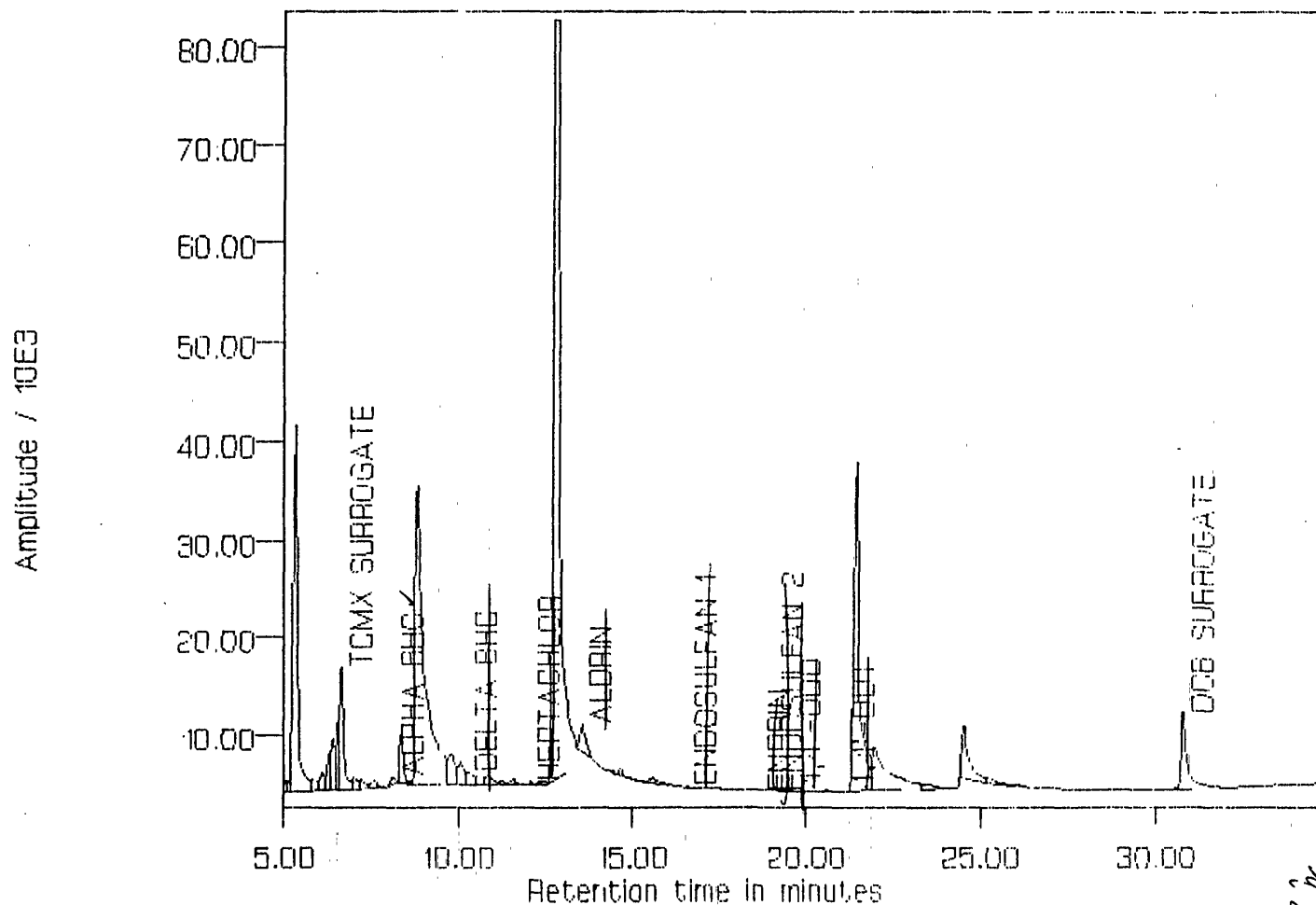
J. Konrad  
Analyst

John L. M.  
Approved

008549

008550

Sample : X74796 [Client#2136-64] Injected : FRI AUG 13, 1993 6:28:21 AM

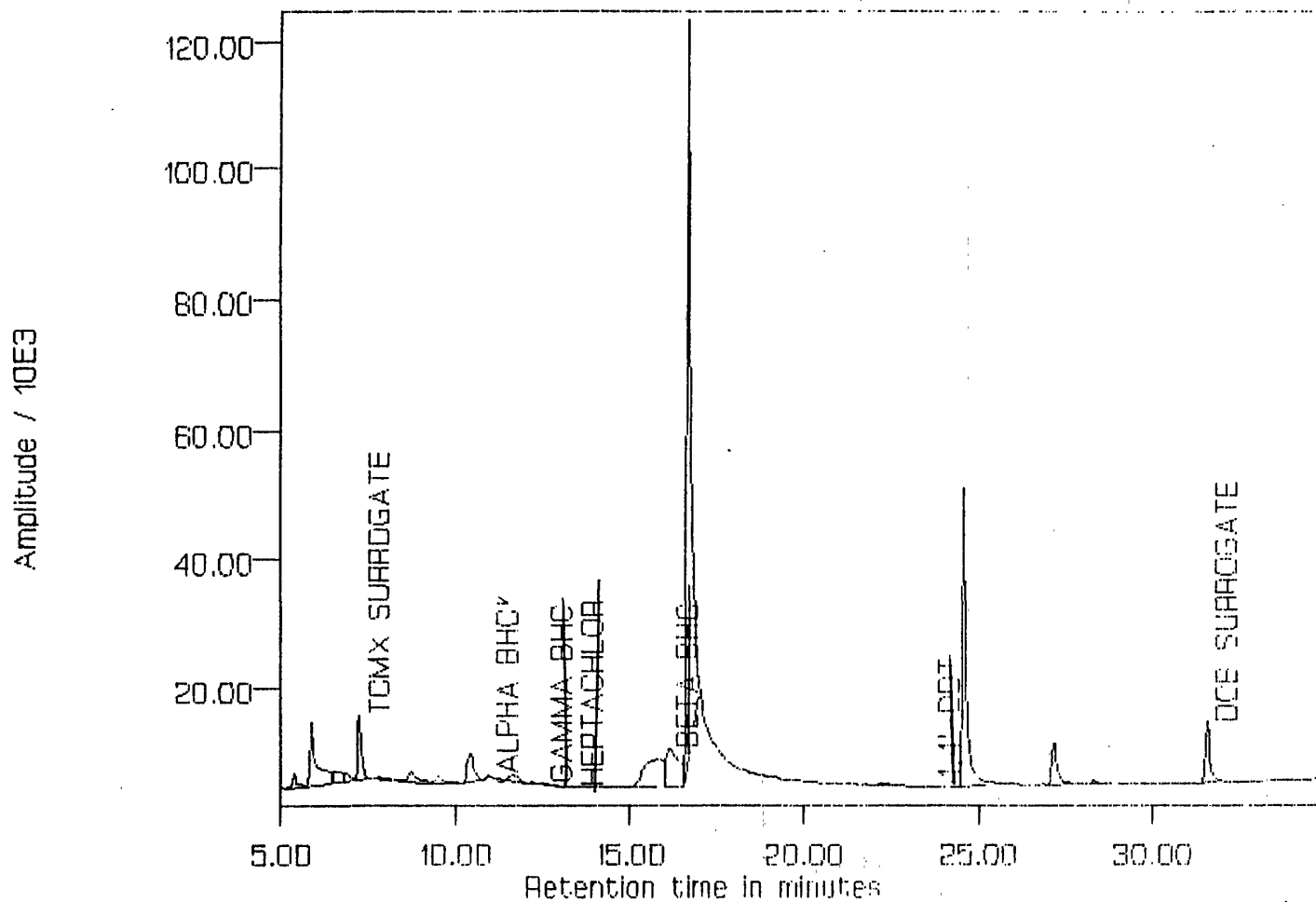


Result : ECD13533

Method : PEST1AUG11

ISS800

Sample : x74796 Injected : FRI AUG 13, 1993 6:28:22 AM



Result : ECD23533

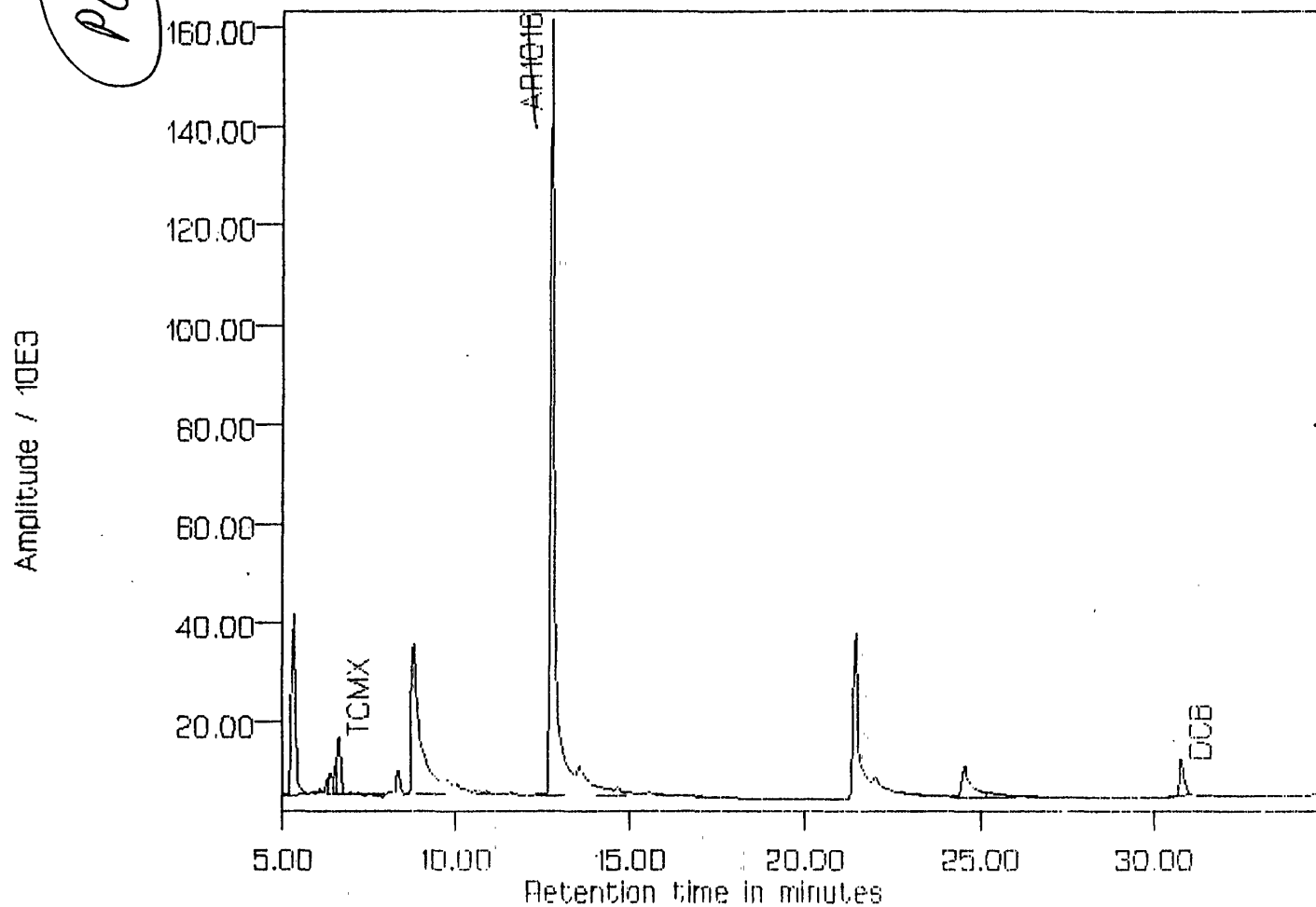
Method : PEST2AUG11

8/19/93 *pe.*

008552

PCB

Sample : X74796 (Client#2136-64) Injected : FRI AUG 13, 1993 6:28:21 AM



Result : ECD13533

Method : AR1016

EVERGREEN ANALYTICAL, INC.  
4036 Youngfield Wheat Ridge CO 80033  
(303)425-6021  
Pesticide & PCB Data  
Method Blank Report

008553

Method Blank Number	: WB081293	Client Project No.	: 8068
Date Extracted/Prepared	: 08/12/93	Lab Project No.	: 93-2741
Date Analyzed	: 08/13/93	Dilution Factor	: 1.000
		Method	: 608
		Matrix	: Water
		Lab File No.	: ECD13530

Compound Name	Cas Number	Concentration ug/L	MDL* ug/L
alpha-BHC	319-84-6	U	0.003
beta-BHC	319-85-7	U	0.006
delta-BHC	319-86-8	U	0.009
gamma-BHC	58-89-9	U	0.004
Heptachlor	76-44-8	U	0.003
Aldrin	309-00-2	U	0.004
Heptachlor epoxide	1024-57-3	U	0.008
Endosulfan I	959-98-8	U	0.01
Dieldrin	60-57-1	U	0.002
4,4'DDE	72-55-9	U	0.004
Endrin	72-20-8	U	0.006
Endosulfan II	33213-65-9	U	0.004
4,4'-DDD	72-54-8	U	0.01
Endosulfan sulfate	1031-07-8	U	0.007
4,4'-DDT	50-29-3	U	0.01
Methoxychlor	72-43-5	U	0.05
Endrin ketone	53494-70-5	U	0.01
alpha-Chlordane	5103-71-9	U	0.05
gamma-Chlordane	5103-74-2	U	0.05
Toxaphene	8001-35-2	U	0.24
Aroclor-1016	12674-11-2	U	0.05
Aroclor-1221	11104-28-2	U	0.05
Aroclor-1232	11141-16-5	U	0.05
Aroclor-1242	53469-21-9	U	0.07
Aroclor-1248	12672-29-6	U	0.05
Aroclor-1254	11097-69-1	U	0.1
Aroclor-1260	11096-82-5	U	0.1

Surrogate Recovery:

TCMX	94%	(QC Reporting Limits 53-112%)
DCB	106%	(QC Reporting Limits 34-106%)

QUALIFIERS:

U = Compound analyzed for, but not detected.

B = Compound found in blank and sample. Compare blank and sample data.

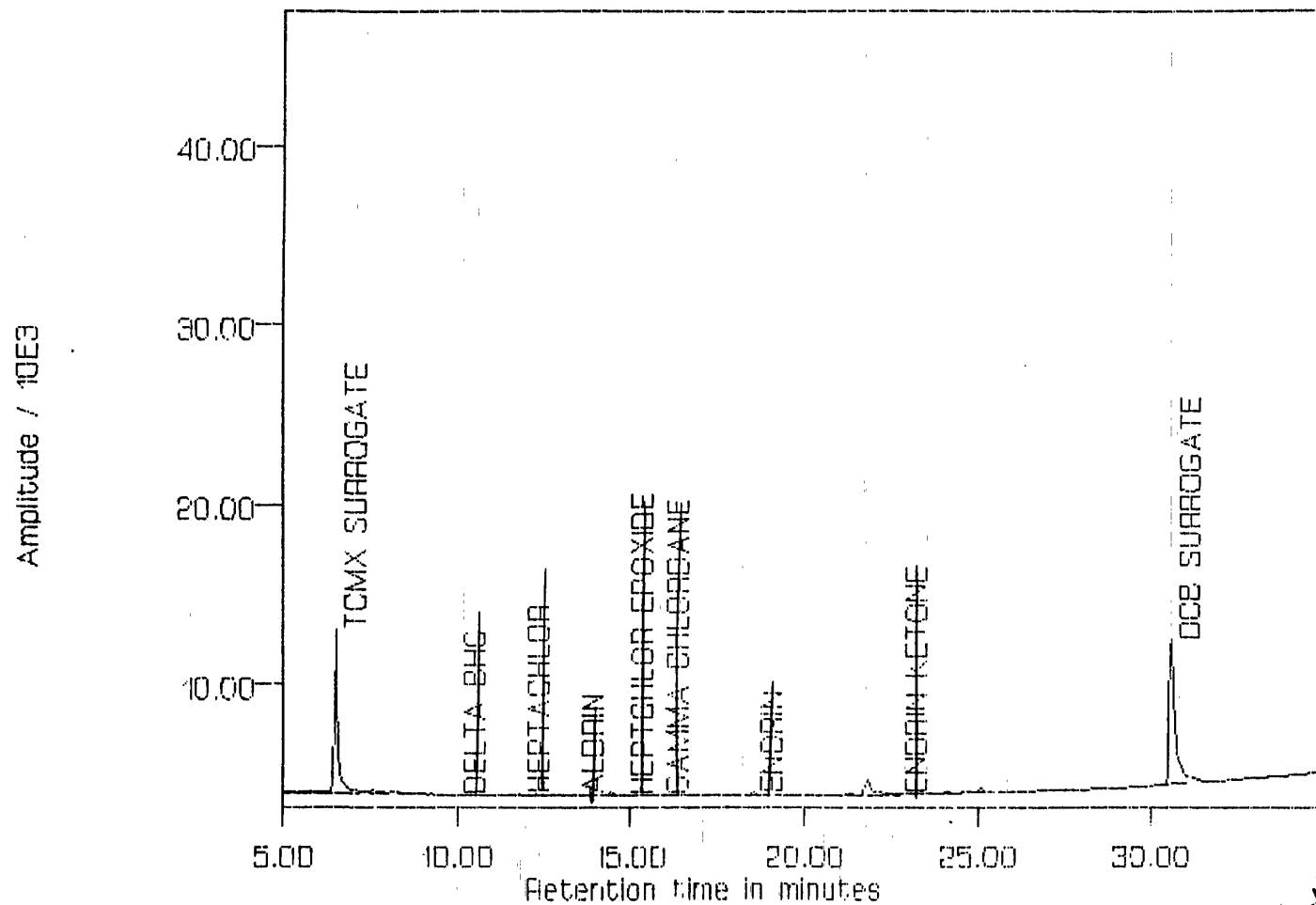
\* = Indicates the Method Detection (MDL). MDLs for Methoxychlor, Endrin ketone, alpha & gamma -Chlordane, and all PCBs except Aroclor-1242 equal one tenth the EPA CLP target quantitation limit.

Korand  
Analyst

Steven H. Hyslop  
Approved

008554

Sample : WBOB1293 Method Blank (93-2741+2802) Injected : FBI AUG 13, 1993



Result : ECD13530

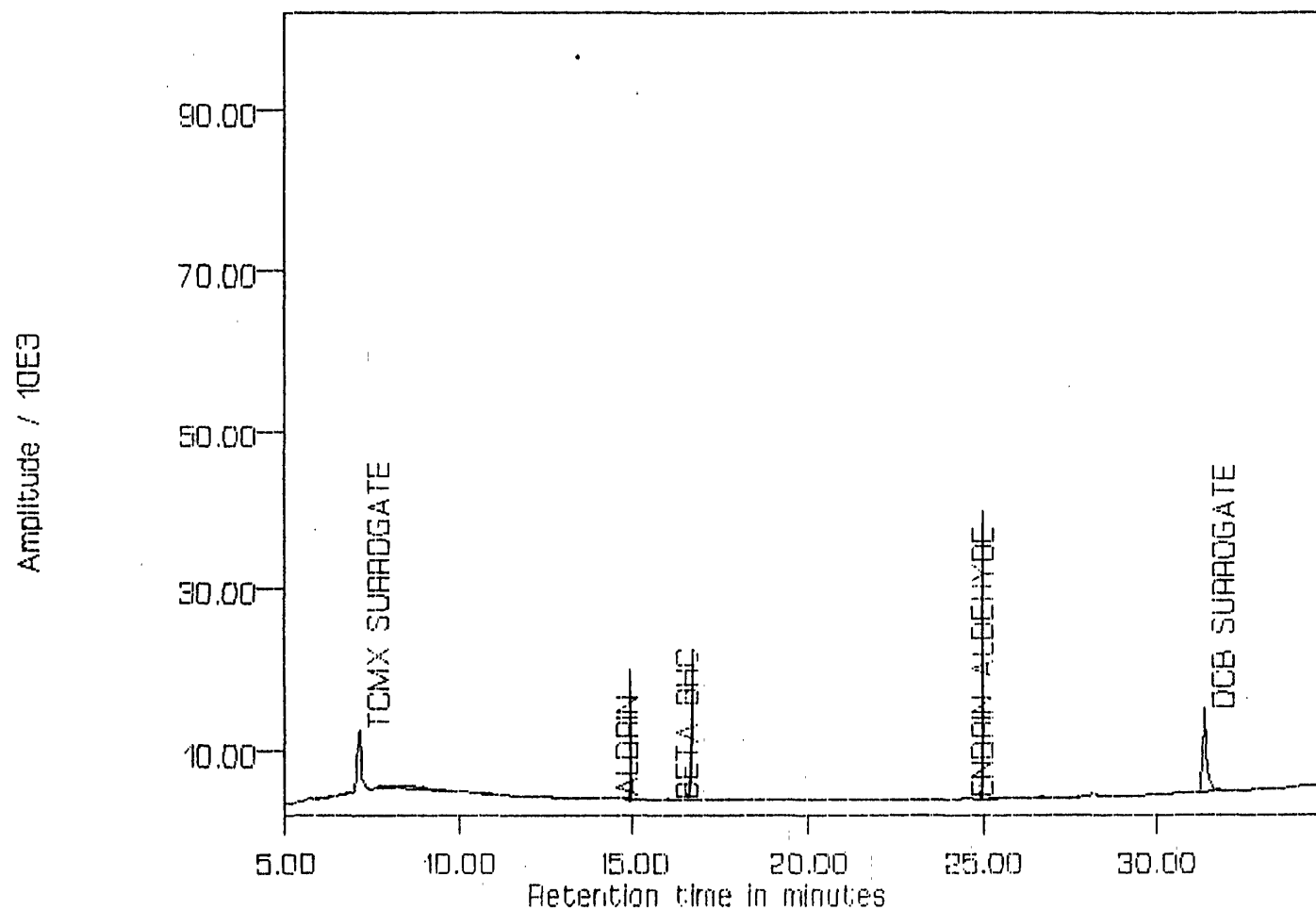
Method : PEST1AUG11

*8/19/83*



008555

Sample : WB081293 Injected : FRI AUG 13, 1993 4:03:34 AM



Result : ECD23530

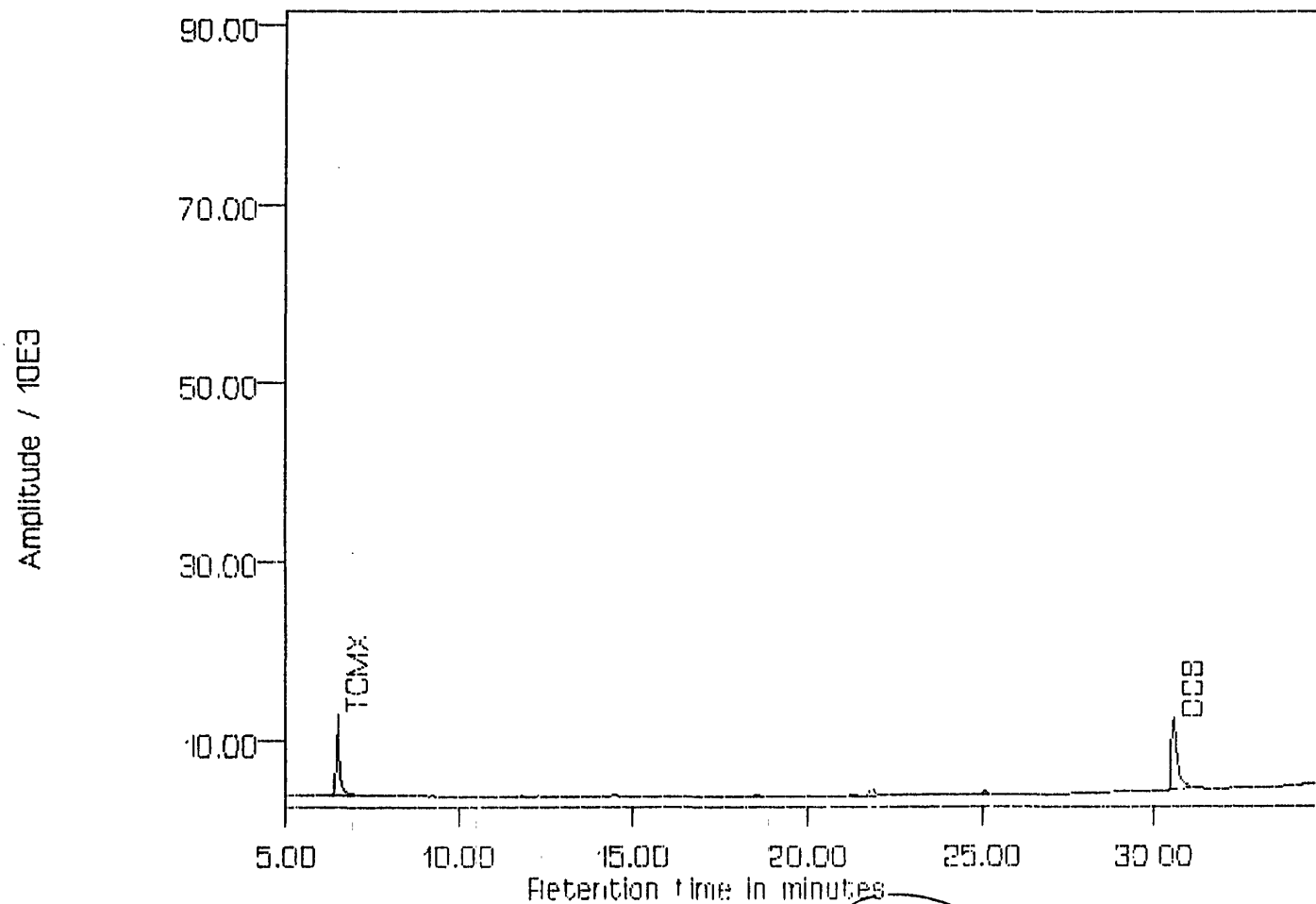
Method : PEST2AUG11

8/19/93 pc

955800

PCB

Sample : WB081293 Method Blank (93-2741+2802) Injected : FRI AUG 13, 1995



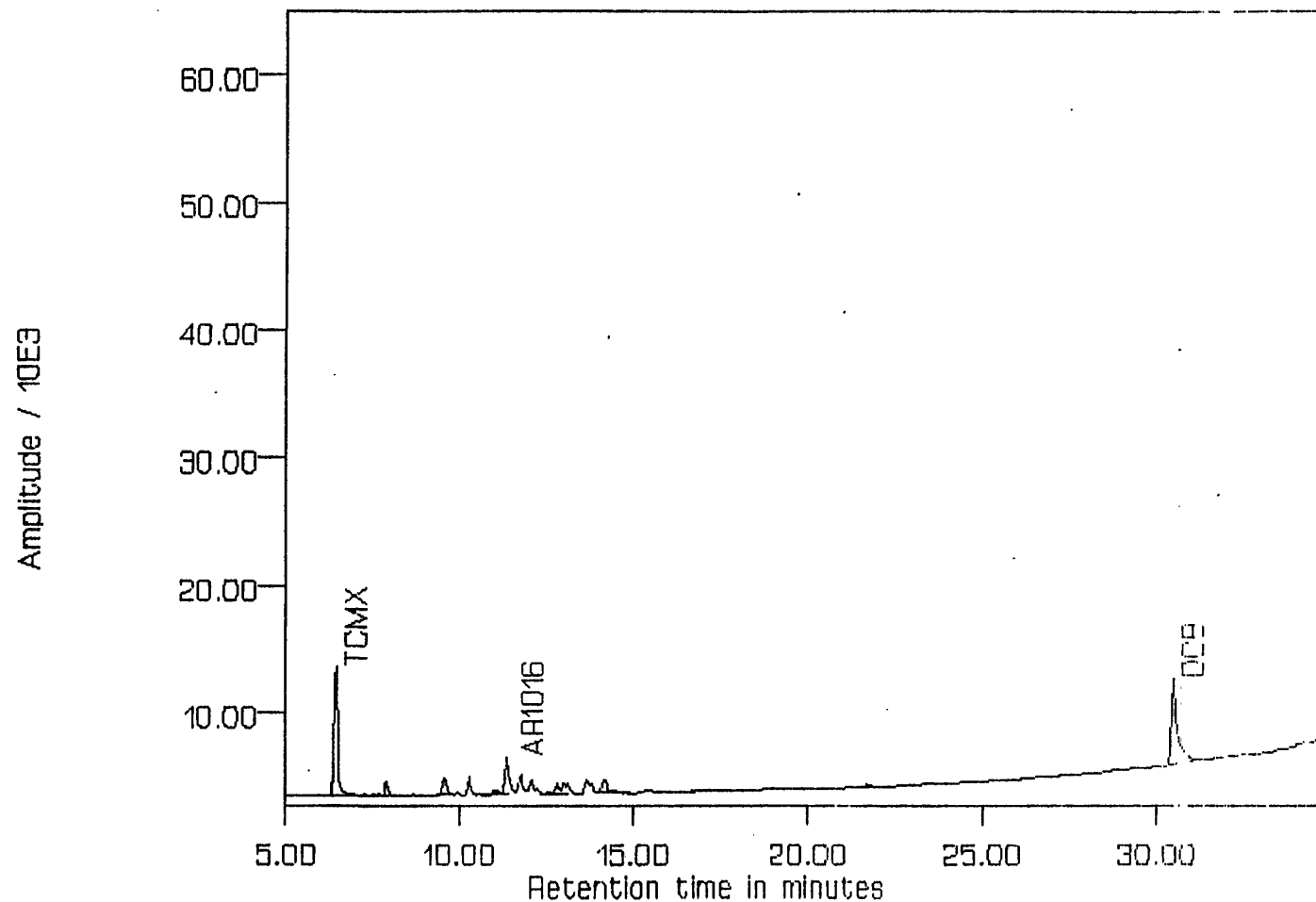
Result : ECC13530

Method : AR1016

LSS800

STANDARD

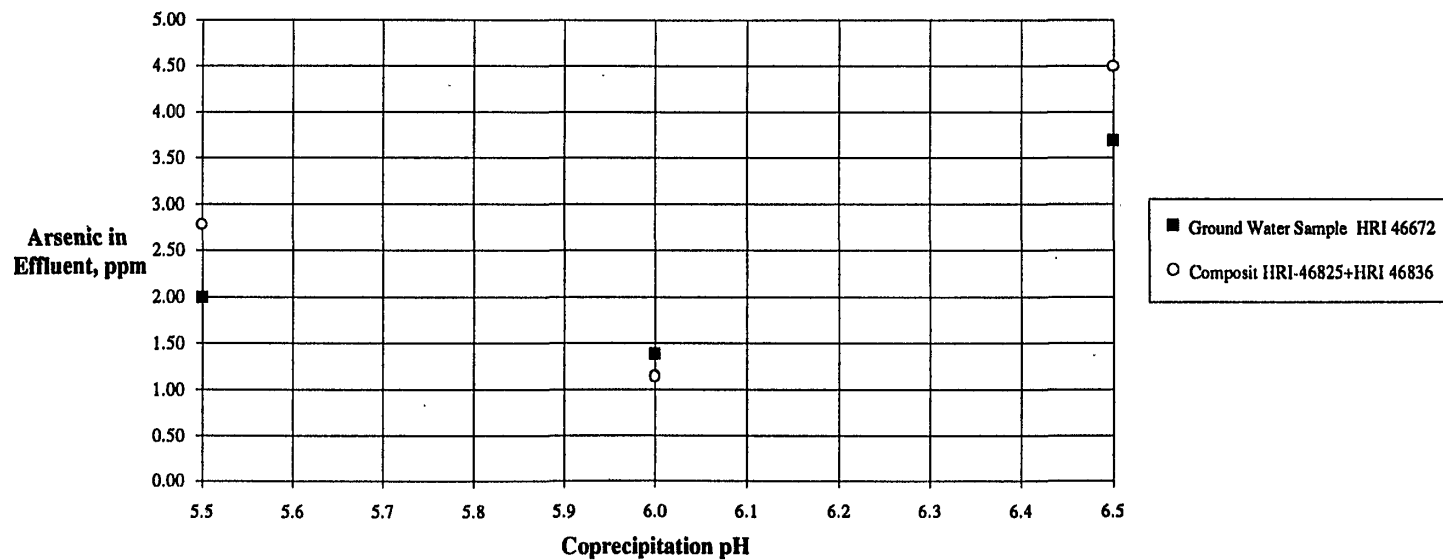
Sample : AR1016 @ 500 ppb    Injected : WED AUG 11, 1993 10:40:01 PM



Result : ECD13493

Method : AR1016

**Effect of Coprecipitation pH on Effluent Arsenic Concentration**  
**2:1 Ferric Iron to Arsenic Weight Ratio**  
**(Assume 150 ppm Arsenic in Feed)**



Actual Arsenic in HRI-46672 was 118 ppm. Recalculated Fe:As weight ratio is 2.5:1.

Actual Arsenic in Composite Sample was 111 ppm. Recalculated Fe: As weight ratio is 2.7:1.

008558

**APPENDIX C**

2/2

008560

Usable with little training for quick approximations . . .

## Worksheet Gives Optimum Conditions

- Handles up to seven process variables.
- All information is on one page or sheet.
- About 12 tests establish optimum process point.
- Designed for quick results in plant or laboratory.
- Extensive background in statistics is not required.

C. H. LI, Radio Corporation of America, Harrison, N. J.\*

Practically all engineers and scientists have to run experiments.

When these experiments involve only two or three factors or variables, they are easily dealt with, although the methods and efficiencies of experimentation vary.

In the "trial and error" or "shot-gun" method, the experimenter selects and makes a few random tests, hoping to hit the best conditions. This method depends very much on intuition and luck. It is not reliable and seldom gives the best results.

The classical method of experimentation involves keeping all factors except one constant, and determining the best condition for this tested factor. The condition for the first factor is then used throughout later tests to find the best conditions for other factors, one at a time. Major disadvantages of this method are: it is inefficient; and it requires as many series of tests as the number of factors under test, which may be very time-consuming.

When an orthodox statistical method is used, a statistician chooses a proper design to test either all possible combinations of the factors, or a systematic fraction of these possible combinations. This method not only finds the effect of all factors, but reveals any possible interactions† between

factors. It is generally very efficient.

There are some disadvantages, however, to some statistical techniques.

Number of tests become too large when many factors are to be studied: either a statistician is needed or the engineer has to be thoroughly trained on this method; a machine calculator is indispensable; and the careful planning and execution of the experiment, as well as the involved analysis of test results cause delays. These delays are often intolerable.

### Box Method Advantages

Recently, a new method of experimentation has been developed, called the Box (or Box-Wilson) method, after the originator G.E.P. Box. It is dynamic, flexible, and yet very efficient.

In this method a series of small experiments are set up so related that results of previous tests are fully used, yet without loss of efficiency common with short-run tests. It has been successful in chemical and other industries.

In principle, the Box method is identical to the familiar scientific method of experimentation, only it is made more systematic by applied statistics. Actually statistical factorial experimental design is an integral part of the method.

As usual, the experimenter sets up and makes some tests, analyzes the results, and makes some more

tests, and so on. But the experimenter uses known techniques of good experimental planning and data analysis, foresees any possible outcomes of the tests, and plans his first experiments with an eye on the last. Each test result is used not just once, but many times to get better means, more accurate average effects, or more reliable conclusions.

### Using the Worksheet

We have developed a worksheet which uses this Box method for finding optimum conditions.

It is designed for engineers or foremen who may not have an extensive background in statistics. The procedure for use is given in a cook-book fashion. Caution should, of course, be exercised, and Ref. 1 pp. 495-578, 263-5 should be looked at.

### Where To Use Sheet

When conditions are suitable, the worksheet may be used in the following cases:

- Trouble-shooting on an urgent research or production problem where quick results and immediate actions are needed.

- Developing a new alloy or composition by finding the effect of all ingredients and their best combinations.

- Designing the proper types of components including their dimensions for best performance of

\* Meet your author on page 181.

† If the effect of one factor is different at different levels of another factor, these factors interact (pressure at two temperature levels).

## Here, Chart Is Used to Find Best High-Strength Alloy

Experiment: *Spiral from Base Alloy* Object: *Find best alloy* Data: *Find best alloy* Date: *10.10.53*

Line	Factors studied	A	B	C	D	E	F	G	Error of single test	I = ABCD
2		Cr	Ni	Mo	V	Nb	Mn	C	$e = 2.43 \times \text{smallest effect}$	-- BCE = --ADE
3	Base level	4%	2%	0.1%	0.02%	0.1%	0.4%	0.4%	Error, effect = $e/8$	-- ACF = --BDF
4	Unit	1	1	0.1	0.02	0.1	0.1	0.1	= 0.354e	-- ABG
5	High level									Interaction of factors
6	Low level	3	1	0	0	0	0.3	0.3		
7	Sample 1 Test 5	3	1	0	0	0	0.3	0.3	1.5	5.0
8	" 2 8			0	0			0.3	3.5	9.4
9	" 3 1		1		0		0.3		6.2	10.4
10	" 4 3	3%			0	0			3.2	11.1
11	" 5 4		1	0		0			5.3	2.0
12	" 6 6	3		0			0.3		5.1	-3.0
13	" 7 2	3	1					0.3	5.3	-0.2
14	" 8 7					0	0.3	0.3	5.8	0.5
15	Effect	0.71	-0.09	0.64	0.89	0.54	-0.16	0.46		
16	Effect times unit	0.71	-0.09	0.064	0.018	0.054	-0.016	0.046		
17	Change	0.8	-0.1	0.07	0.02	0.06	-0.02	0.05		
18	Best path	4.8	1.7	0.17	0.04	0.16	0.38	0.45		
19		5.6	1.8	0.24	0.06	0.22	0.36	0.50		
20		6.4	1.7	0.31	0.08	0.28	0.34	0.55		
21		7.2	1.6	0.38	0.10	0.34	0.32	0.60		
22	Trial 9	8.0	1.5	0.45	0.12	0.40	0.30	0.65	10.3	
23		8.8	1.4	0.52	0.14	0.46	0.28	0.70		
24	Trial 10	9.6	1.3	0.59	0.16	0.52	0.26	0.75	11.0	
25	Trial 11	10.4	1.2	0.66	0.18	0.58	0.24	0.80	11.5	
26	Trial 12	11.2	1.1	0.73	0.20	0.64	0.22	0.85	11.2	
27	Trial 13	12.0	1.0	0.81	0.22	0.70	0.20	0.90	10.1	

Conclusions:  
Best composition (trial 11)  
Cr 10.4%  
Ni 1.2%  
Mo 0.66%  
V 0.18%  
Nb 0.58%  
Mn 0.24%  
C 0.80%

Expected tensile strength:  
11,500 ± 240 psi.

a given mechanical or electrical device.

- Improving a production process on yield, cost, or product quality.

- Scanning a great number of factors or controllable variables for the most important few to be closely studied.

- Setting-up the first runner of a possibly large project, to be effectively supplemented by future tests when needed.

The worksheet is self-contained. All the response and control variables, details of data analysis, precision of tests, and other important conclusions are given on a single page.

It applies the Yates method of data analysis. Calculations are simple enough so an engineer or foreman can do them in a few minutes, without machine calculators. The Yates method is a systematic tabular technique for

evaluating the effect of four or more factors.

Up to seven factors can be tested with a single worksheet. Fewer factors should be selected, however, if they interact.

It uses the Box method for examining response surfaces; and following the steepest ascent line to the optimum point.

Only four or eight tests are needed to establish the response contours and to find the effect of various factors. These tests may be followed by a few more tests to reach the maximum point.

The worksheet may be used in a sequential manner. A group of four tests may first be run to study up to three factors. A second group of four more tests may, if desired, next be made, not only to study up

Just as the relationship between  $y$  and a single factor  $x$  can be represented by a curve, the relationship between  $y$  and a number of variables can be shown with a surface, called a response surface.

to four more factors, but also to improve the conclusions from the first group of tests. Response surfaces may be examined and the steepest ascent method applied for each or both of the two groups of four tests (or confirmation experiment in which the same factors are assigned to different columns on the worksheet). Contradictory results from the two experiments may reveal interactions.

The response surfaces are usually not too complicated. Most response surfaces known for actual systems have one or two maximum peaks, and the response contours are not difficult to establish. If complex response surfaces do exist in the small experimental region, erroneous conclusions may be drawn. The possibility of reaching wrong conclusions, however, is ever present with any method of experimentation when the system of factors is complex. Here again,

# Same Chart Gives Process Conditions for Low Rejects

Line	Experiment: Processing part 5-N	Object: Minimum rejects	Date: 4/1/58	Date:
1	Factors studied	A B C D E F G	Error of single test 2024 $e = 2.43 \times \text{smallest effect}$ Error, effect = $e/2$ $= 0.354e$	I = ABCD $= -ACE = -ADE$ $= -ACF = -BDF$ $= -ABG$ Interaction of factors
2	Base level	150C - 151b - 350m 9 15m		
3	Unit	50 - 5 - 50 3 5		
4	High level			
5	Low level	100 70 10 #1 300 6 10	H J K L M N	
6	Sample 1	Test 1 100 70 10 #1 350 6 15	Data Calculation Effect Effect of Each Factor	
7	2	2 100 70 10 #1 350 6 15	12 16 28 Average 7.0 Average	
8	3	3 100 70 10 #1 350 6 15	4 12 -6 B -1.5 B	
9	4	4 100 70 10 #1 350 6 15	5 -8 -4 C -1.0 C	
10	5	5 100 70 10 #1 350 6 15	7 2 10 -A 2.5 BC = AD - E	
11	6	6 100 70 10 #1 350 6 15	8 13 23 Average 5.8 ABC = 0	
12	7	7 100 70 10 #1 350 6 15	5 10 -1 B-F -0.2 AC + BD = -F	
13	8	8 100 70 10 #1 350 6 15	4 -3 -3 C-G -0.8 AB + CD = -G	
14	Effect	-2.5 -1.5 -1.0 -0.6 -9.7 -1.3 -0.2	6 2 5 A-E 1.2 A	
15	Effect times unit	-7.5 - - -0.5 - -18.5 3.9 -1.0		
16	Change	2.5 - 1.7 - 6.2 1.3 0.3		
17	Best path	17.5 46 16.7 #2 4.2 10.3 15.3		
18		200 46 18.4 #2 4.74 11.6 15.6		
19	Trial 9	225 46 20.1 #2 5.26 12.9 15.9 2		
20	10	250 46 21.8 #2 5.78 14.2 16.2 1		
21	11	275 46 23.5 #2 6.60 15.5 16.5 0		
22	12	300 46 25.2 #2 7.22 16.8 16.8 2		
23		325 46 26.4 #2 7.84 18.1 17.1		
24				
25				
26				
27				

## Conclusions:

Effects:  $D = (5.8 - 7.0)/2 = -0.6$   
 $E = A - 1.2 = -3.7$   
 $F = B + 0.2 = -1.3$   
 $G = C + 0.8 = -0.2$

## Best combination (Trial 11)

Preheat temp. 275C.  
 Cleaning 46  
 Reagent added 23.5 lb.  
 Additive #2  
 Pressure 660 psi.  
 Voltage 15.5 v.  
 Treat time 16.5 min.

special confirmation tests may be needed.

## Assumptions in Design

Design of the worksheet is not complicated. The eight treatment or factor combinations (one for each sample) are selected from an orthodox statistical design given in Table 10A.1 on p. 485 of Ref. 1. Technically, it is called a  $2^k$ -replicate of a seven-factor design, each factor having two levels or conditions tested (see charts).

Note that eight combinations are arranged for data analysis either simultaneously on all eight test results, or separately on the first or second group of four test data.

Effects of various factors, as indicated by the Yates method, are used to locate the steepest ascent and to find the maximum point in a few more tests. This section is on the bottom-half of the sheet.

A number of assumptions were made in design of the worksheet.

First, precision of tests or experimental error is small. If the error is not small, tests may have to be repeated. Each sample number then becomes a sample group number.

Data or test results are normally distributed. However, abnormal data may be transferred into normal data. If the tests are repeated, particularly if repeated a number of times, the averages from any data become nearly normal.

When four or more factors are tested with a single worksheet, it is assumed that interactions among these factors either are absent or are very small. This assumption is generally true.

If interactions exist, fewer factors should be put in each experiment. For example, if three factors are tested all main effects and interactions can be estimated;

whereas if four factors are tested with the same number of samples, only one pre-specified interaction is lost.

## Let's Work Examples

The use of the worksheet is best illustrated by analysis of the following two hypothetical examples. (1) find the best composition of an alloy for a special use; (2) optimize a certain process for minimum "scrap" or cost.

Example 1: Develop an alloy design for very high hot strength. For this particular use, cost considerations indicate that an iron-base material is desirable. Additions of various elements will be made to achieve the desired properties, including chromium, nickel, molybdenum, vanadium, niobium, manganese, and carbon.

The following steps are involved in the procedure (see chart):



1. Name and object of the experiment are first entered, together with the data to be taken and the date.

2. Elements, the amounts of which will be varied, are entered as factors A to G. Metallurgical and economic considerations determine the base levels and units or variation for some elements. For the other elements, these values are estimated. The high levels (shaded in the worksheet) are obtained by adding the units of variation to the respective base levels, and the low levels by subtracting the units of variation from the base levels.

3. Because the number of factors in this problem is seven, eight tests must be made. The number of tests must be at least one greater than the number of factors.

4. Order of test is determined by the random drawing of eight numbered chips and the recording of the numbers drawn in sequence. If chip 3 is drawn first, for example, test 1 is to be made on sample 3.

5. Each sample is composed of high- or low-level amounts of the various elements, as indicated by the presence or absence of black in the worksheet. Sample 1, for instance, has low levels of all elements. Sample 2 has high levels of chromium, nickel, niobium, and manganese, but low levels of molybdenum, vanadium, and carbon. To fill in this information on the composition of the different samples, it is convenient to work through each element or column at a time, filling in the four shaded spaces on the worksheet with the high-level conditions, and then the remainder with the four low-level conditions.

6. Samples are prepared by special melting and mechanical working in the assigned order. They are then tested for the desired property—tensile strength at 800 C. Test data are entered in column H.

7. Results of the eight tests are analyzed by the Yates method. First, the results are divided into four consecutive pairs. The two numbers in each pair are then added together to give the first four figures in the J column ( $1.5 + 3.5 = 5.0$ ;  $6.2 + 3.2 = 9.4$ ;  $5.3 + 5.1 = 10.4$ ;  $5.3 + 5.8 = 11.1$ ). And the first number of each pair is subtracted from the second to give the last four figures in the J

column ( $3.5 - 1.5 = 2.0$ ;  $3.2 - 6.2 = -3.0$ ;  $5.1 - 5.3 = -0.2$ ;  $5.3 - 5.3 = 0.5$ ). These processes are repeated on column J to obtain the values for column K, and repeated on column K to obtain column L. The values in column L are then divided by the number of tests (i.e., 8) to yield the figures for the "effects" column, M. The effects are identified by letter symbols in the last column, N.

8. Effects listed in columns M and identified in column N are entered in line 15, with caution as to signs (plus or minus) and positions (A to G).

9. Preliminary conclusions are first, the average tensile strength at 800 C. for the eight samples is 4,490 psi. This value is the expected hot strength of a sample having all alloy additions at the base levels, i.e., 4% Cr, 2% Ni, 0.1% Mo, 0.02% V, 0.1% Nb, 0.4% Mn, and 0.4% C.

Second, vanadium appears to have the greatest effect, increasing the hot strength by 890 psi. for each 0.02% added. In other words, each 0.1% of vanadium added raises the hot strength by 4,450 psi.

Chromium, molybdenum, niobium, and carbon increase the hot strength by 71, 640, 540, and 460 psi., respectively, for each 0.1% of alloy addition. Manganese and nickel, however, probably have little or slightly negative effects on the hot strength.

Probable error of a single test is estimated by examination of the smallest effects, in this case 0.09 or 90 psi. due to addition of nickel and 0.16 or 160 psi. due to manganese. For this problem, the error is of the order of 240 [90 (8)<sup>1/2</sup>] psi. (if nickel has no effect at all) or less.

The Box method of "steepest ascent" may now be applied if desired. In this method, a few additional tests located on the line of expected maximum response are selected, and the following extra steps are taken:

10. Effects in line 15 are multiplied by the respective units of variation in line 4, giving line 16. If it is desired to change the unit of variation for one of the elements to a more convenient amount (chromium, for example, may be varied in the additional tests by 0.8% rather than the odd number 0.71%), all the values in line 16

must be changed proportionately by the same factor (e.g.,  $0.8/0.71 = 1.13$ ) to yield line 17.

11. The best path is then determined by successive additions the proposed changes in line 17 the corresponding base levels ... line 3. Thus, line 18 = line 3 + line 17; line 19 = line 3 + (2 x line 17); line 20 = line 3 + (3 x line 17); and so on.

12. An extra melt is made according to the composition given in line 22, which is considerably different from the base-level conditions. Because of the encouraging result of 10,300 psi., melt 10 (line 24) is made, followed in order by melts 11, 12, and 13 (line 25, 26, and 27). The results of hot-strength tests on all these additional melts are entered in column H.

13. By inspection, it is seen that the maximum hot strength is reached on melt 11. Consequently, the best composition is as follows: 10.4% Cr, 1.2% Ni, 0.66% Mo, 0.18% V, 0.58% Nb, 0.24% Mn, and 0.80% C. The expected hot strength of this combination is  $11,500 \pm 240$  psi.

### Sequential Example

*Example 2:* Processing design for minimum rejects. A number of processing factors are likely to affect rejects of a certain product. Some of these factors are listed below, together with the suggested low- and high-level conditions:

Factor A: Prefire temperature—100 vs. 200 C.

Factor B: Special cleaning—no cleaning vs. cleaning.

Factor C: Amount of reagent added—10 vs. 20 pounds.

Factor D: Special additive—Additive #1 vs. #2.

Factor E: Applied pressure on a certain equipment—300 vs. 400 lb.

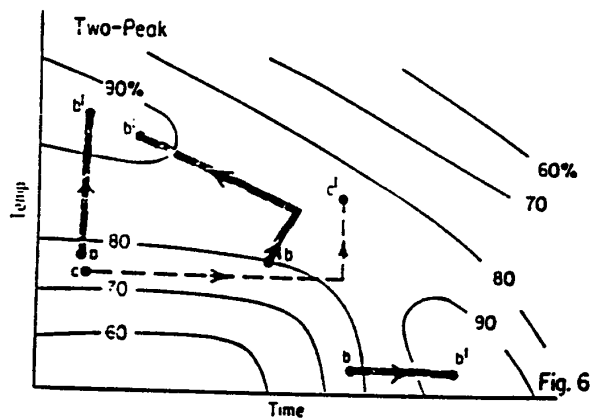
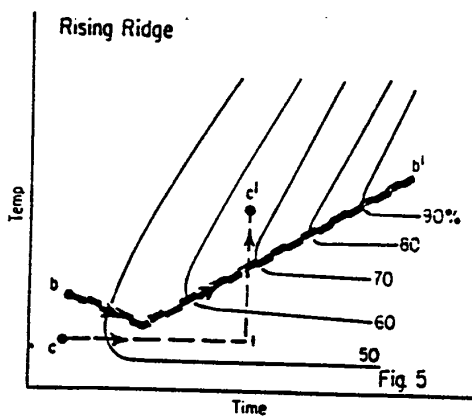
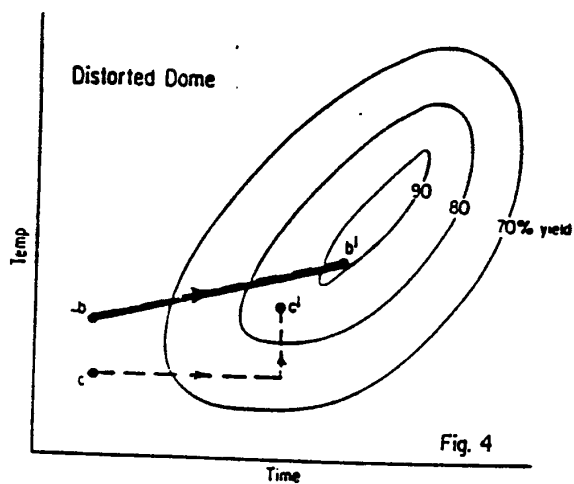
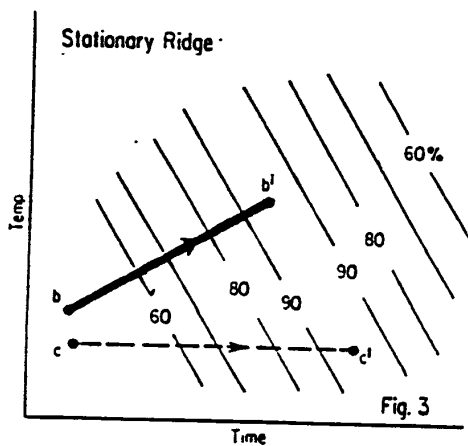
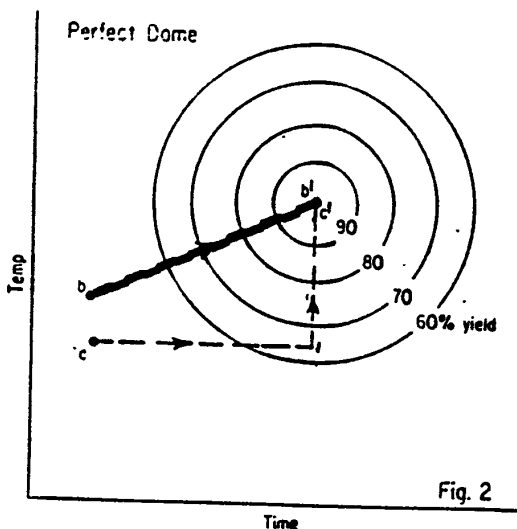
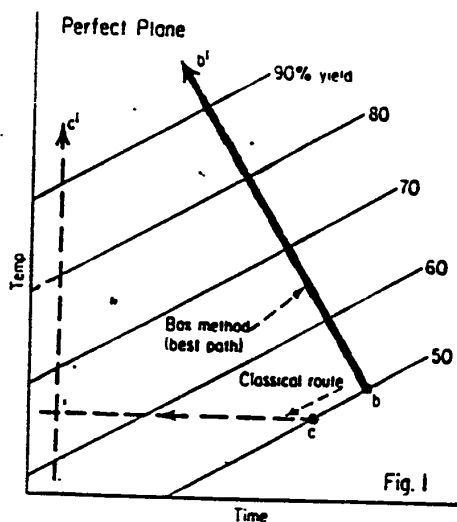
Factor F: Applied voltage on another equipment—6 vs. 12 volts.

Factor G: Treatment time—10 vs. 20 minutes.

The experimental design may be as follows: At first, four tests are made on samples 1 to 4, in the random order 4, 2, 1, 3.

Factors A, B, and C are varied, other factors being kept constant: D at the low level; E, F, and G at the base levels, in order to fully use the worksheet. The data analysis is similar to that in Example

# Steepest Ascent Method Best for Obtaining Optimum Conditions



1, except that only two, instead of three, cycles of arithmetic operations are involved, each on four figures, rather than eight. The average effects found are  $A = -2.5$ ;  $B = -1.5$ ; and  $C = -1.0$ . The negative signs indicate that these factors all tend to reduce the scrap figure, factor A being the most effective.

The above conclusions may be used as such. However, it may be decided to introduce the four additional factors D, E, F, and G. Only four more tests are next made on samples 5 to 8. The average effect of these additional factors can be found as shown.

Finally, the method of steepest descent can be applied if needed.

As shown on the sheet, four trials were attempted on the path of steepest ascent. Trial 11 resulted in zero rejects. Final or best combination for the process: prefire temp., 275 C.; cleaning preferred; reagent added, 23.5 lb.; additive no. 2; pressure, 660 psi.; voltage, 15.5 v.; treat time, 16.5 min.

Actually this is an approximation of the best combination, good enough for most situations. Techniques are available for obtaining a more accurate "best" combination, calling for additional experiments.

### More On Box Method

Plant managers and project engineers should like the Box method we discussed because it gives useful conclusions from the very first few tests made. The tests can therefore, be stopped at any moment, such as when facilities on the project are suddenly curtailed. Yet more tests can also be efficiently added as complexities or the needs for details arise.

We will not attempt to go into the mathematical derivations for this method. It is strongly suggested that you read Ref. 1 for a practical treatment of optimizing methods.

We will give some important highlights which should give you an idea of what is involved and where this technique can be used to advantage.

### Response Surfaces

A useful concept brought in by the Box method is the response

surface. Engineers have always been dreaming of showing the desired changes on the response variables, such as yield, quality, and cost, in spatial relationship with the various factors. By the use of the Box method, these response surfaces can be established, with but a few tests.

Only response surfaces for two factors are shown here. A common way of showing these response surfaces in graphical form is to draw lines of equal responses on these surfaces. These lines or response contours are like similar lines on weather or topography maps. Some typical examples of response surfaces are shown in the following figures, which also compare the Box method with the classical one-factor method of experimentation under the various conditions (see p. 155).

All these figures show the variation of yield with temperature and time. Yield is the response variable, while temperature and time are the factors or control variables.

Fig. 1 shows a case where the response surface for yields is a perfect plane. Response contours or lines of equal yields are therefore parallel, straight lines.

The classical experimenter would probably start testing at point *c* by varying the time but keeping temperature constant. A first series of constant-temperature tests along line *c-t* locates the temporary maximum point *t*.

Maximum point *c* is reached after a second series of constant-time tests along line *t-c*. The experimenter using the Box method would set up four tests around starting point *b*, and add a few more tests on the steepest ascent line *b-b'*. Both experimenters would reach the same maximum yield. The classical experimenter, however, must make more tests to reach the same goal.

When the response surface is dome-shaped, the response contours may be concentric circles. Such a case is shown in Fig. 2. In Fig. 3, the response surface is a stationary ridge, the yield being maximum on the inclined ridge line and decreasing as the distance from this ridge line increases. The same notes given in Fig. 1 apply in both cases shown by Figs. 2 and 3.

Fig. 4 shows a situation where the response contours are a series

of ellipses. In this case, the classical experimenter may make many tests without reaching the maximum yields.

The response contours shown in Fig. 5 are for a response surface of the rising-ridge type. Here again, the classical experimenter may miss the maximum yields. Using the Box method, you locate a temporary maximum point from which the true maximum yield *b'* is reached by tests along the new steepest ascent line.

Fig. 6 shows a case where the response surface has two regions of maximum yields. In this instance, the classical experimenter may miss both of them. The Box method insures reaching either or both of them no matter where the tests are started.

### What Can Method Do?

In summary, the Box method consists of:

- Running a few selected tests around a chosen point within the experimental region.
- Analyzing the test results to find effects of the various factors.
- Establishing from the same results the response surface and contours in and near the tested area.
- Marking the line from the chosen experimental center to climb the response surface at maximum rate. This line is at right angles to all response contours crossed, and is therefore called the line of steepest ascent.
- Making some more tests along this line to reach the maximum point on the response surface. This step ends the first cycle of experimentation by the Box method.
- If desired, a second cycle may be started around this maximum as the new experimental center, to see if further improvement is possible. More accurate response contours may be established around this new center, and another line of steepest ascent drawn across these response contours, followed by actual tests selected on this line.

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GRAVITY SEDIMENTATION  
AND  
PULP RHEOLOGY STUDIES

CONDUCTED  
FOR

HAZEN RESEARCH, INC.

PROJECT NO. 8316

ARSENIC REMOVAL PROJECT

MAY 1994

PREPARED BY:

POCOCK INDUSTRIAL, INC.  
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## **EXECUTIVE SUMMARY**

Results of the testing program reported herein support the following conclusions:

1. A medium to high molecular weight, nonionic polyacrylamide flocculant can be used to enhance the settling characteristics of ferric hydroxide precipitate generated using ferric chloride or ferric sulfate as the iron source.
2. Design of conventional and solids contact clarifiers for duty on ferric hydroxide precipitate generated using ferric chloride should be based on the following criteria:
  - a. Rise Rate of 0.45 gpm/ft<sup>2</sup> for the production of 1.0% - 1.5% solids underflow.
  - b. Fresh feed solids concentration in the range of 0.02% - 0.08%, at pH 6.0.
  - c. Nonionic flocculant dosage in the range of 1.0 - 3.0 mg/l.
  - d. Detention time required to achieve design underflow solids concentration will be in excess of 120 minutes.
  - e. Supernatant will be clear at the design Rise Rate and flocculant dosage.
3. Design of conventional and solids contact clarifiers for duty on ferric hydroxide precipitate generated using ferric sulfate should be based on the following criteria:
  - a. Rise Rate of 1.0 gpm/ft<sup>2</sup> for the production of 2.0% - 3.0% solids underflow.
  - b. Fresh feed solids concentration in the range of 0.02% - 0.08%, at pH 6.0.
  - c. Nonionic flocculant dosage in the range of 0.50 - 0.75 mg/l.
  - d. Detention time required to achieve design underflow solids concentration will be in excess of 120 minutes.
  - e. At design conditions, production of clear supernatant will require the efficient flocculation and solids capture characteristics of a solids contact clarifier.

4. Solids concentration is a primary factor influencing the apparent viscosity of thickener underflow pulps. Apparent viscosity may limit design underflow concentrations.

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## **INTRODUCTION**

Gravity sedimentation and pulp rheology tests were conducted on samples of ferric hydroxide precipitate produced under Hazen Research, Inc. Project No. 8316. The samples were produced during treatability and flow sheet development studies conducted by Hazen Research, Inc. The range of samples tested is discussed in the Scope of Testing section which follows.

Present investigations were conducted at the Hazen Research, Inc. laboratory facilities during May 1994. The responsibility for the selection of samples to be tested was borne by Hazen Research personnel. Accordingly, samples presented to Pocock Industrial for testing were assumed to represent material likely to be encountered in an operating plant and thus, form the basis for the analyses and recommendations reported herein.

## **SCOPE OF TESTING**

The scope of the testing program included the following:

### **A. Flocculant Screening and Evaluation.**

#### **1. Materials.**

- a. Ferric Hydroxide Precipitate.**
  - i. Ferric Chloride as Ferric Source.**
  - ii. Ferric Sulfate as Ferric Source.**

#### **2. Determinations.**

- a. Examine the relative effectiveness of flocculants of varying charge, charge density and molecular weight.**

### **B. Static Clarification Studies.**

#### **1. Materials.**

- a. Ferric Hydroxide Precipitate.**
  - i. Ferric Chloride as Ferric Source.**
  - ii. Ferric Sulfate as Ferric Source.**

2. Determinations.

- a. Static clarification tests to examine flocculation, hydraulics, Rise Rate and Unit Area requirements and to predict underflow solids concentration for clarifiers.

C. Pulp Rheology Studies.

1. Materials.

a. Ferric Hydroxide Precipitate.

- i. Ferric Chloride as Ferric Source.  
ii. Ferric Sulfate as Ferric Source.

2. Determinations.

- a. Rheology tests to determine the apparent viscosity of clarifier underflow at known shear rates relative to solids concentration.

## TEST EQUIPMENT

### GRAVITY SEDIMENTATION

#### Static Clarification Tests

Static gravity sedimentation data were collected in two-liter graduated cylinders for sizing conventional clarifiers.

Classical Kynch-type clarification/thickening tests were conducted in two-liter graduated cylinders. The aforementioned cylinders were fitted with slow turning picket rake mechanisms. Picket rakes serve to simulate the rake action found in full-scale clarifiers and thickeners in that they reorient floccule particle bridging and hydraulic channeling. Picket rakes also minimize the wall effects imparted by the narrow cylinder. In the two-liter tests, flocculant was added with a pipette which had an inverted stopper affixed to the delivery end to promote thorough mixing.

## PULP RHEOLOGY

### Viscosity Tests

Viscosity data were collected with the use of a Brookfield Model LVT rotating viscometer with cylindrical spindles.

The viscometer rotates a spindle and measures the torque required to overcome the viscous drag of the fluid by recording the point at which rotation begins. The immersed spindle is driven through a calibrated spring, which in turn is driven by a synchronous motor. The degree to which the spring compresses to overcome the viscous resistance is proportional to the viscosity of the fluid.

The defined geometry provided by cylindrical spindles facilitates calculation of shear stress and shear rate. The shear stress, a shear force across an area of contact is a function of the spindle dimensions and the torque developed by compression of the spring during rotation. The shear rate or velocity gradient is a function of the deformation properties of the fluid. For Newtonian fluids, the shear rate is proportional to rotational speed and spindle radius. However, since the apparent viscosity of non-Newtonian fluids changes with shear rate, the deformation properties of the fluid cannot be directly measured. A multiple number of apparent viscosities at specific shear rates are required to characterize non-Newtonian fluids.

## TEST METHODS

### FLOCCULANT SCREENING

Prior to conducting any sedimentation tests on the pulps listed above, flocculant screening tests were conducted on small samples of each to determine the relative effectiveness of each flocculant in areas such as floccule particle formation, the capture of fines, liquor release and the approximate dosage level required.

Screening tests were performed at each typical fresh feed solids concentration. The concentration of the various flocculants examined was 0.05 g/l active polyelectrolyte.

It is noted that the purpose of the screening tests conducted was not to determine the specific or optimum flocculant for usage in the plant, but rather, the purpose was to select the flocculant whose generic type would most likely be effective in plant operation, and therefore, suitable for solids/liquid separation testing.

## GRAVITY SEDIMENTATION

### Static Clarification Tests

The two-liter cylinder was filled to the appropriate mark with pulp known to yield a given (feed) solids concentration upon complete filling with dilute flocculant solution. Flocculation of the pulp was accomplished by adding the flocculant with the pipette/stopper arrangement described above.

Collected data consisted of pulp interface height as a function of time, flocculant concentration and dosage, temperature, pH, solids inventory within the cylinder and initial and final solids concentrations.

## PULP RHEOLOGY

### Viscosity Tests

Multiple viscometer dial readings, over a range of spindle speeds, were taken from pulp samples produced during bench-scale gravity sedimentation testing. The initial dial reading was taken at a relatively low spindle speed. The speed was then incrementally increased until the dial reading exceeded 100. Dial readings are then generally taken through a decreasing progression of spindle speeds to examine the time dependent nature of fluids. The procedure is then repeated, if possible, with a second spindle size.

The inherent tendency of slurry suspensions to continue to settle during viscosity testing necessitates recording multiple dial readings at each spindle speed with gentle agitation of the pulp at each speed change. Hence, the time dependent nature of slurry suspensions cannot be examined.

## DATA PRESENTATION AND DISCUSSION

All collected and correlated data are recorded in the Appendix.

## FLOCCULANT SCREENING

Each flocculant under test was added in turn to samples of the appropriate pulp in a drop by drop fashion while gentle agitation was produced with a spatula. The amount of flocculant required to initiate floccule particle formation, or pinpoint floccule, was noted along with relevant notes as to the size of the floccules, the capture of fines, liquor release and the resultant supernatant quality and stability of the floccule structure.

Screening tests conducted on ferric hydroxide precipitate generated using ferric chloride and ferric sulfate as the iron ion source, as shown in Tables A through F, indicated that a medium to high molecular weight, nonionic polymer, similar to Percol 351, should be employed to produce clear supernatant and rapidly settling particles.

## GRAVITY SEDIMENTATION

### Static Clarification Tests — Conventional and Solids Contact Clarifier Sizing

Classical Kynch-type clarification/thickening tests were conducted for sizing conventional thickeners. Data collected from tests conducted on ferric hydroxide precipitate generated using ferric chloride and ferric sulfate as the iron ion source are summarized in Table G, in the Appendix.

#### Ferric Hydroxide Precipitate (Ferric Chloride Iron Source)

Gravity sedimentation data collected on ferric hydroxide precipitate produced using ferric chloride as the source for iron are recorded in Tables I - IX and Figures 1 - 9, in the Appendix.

Tests were conducted at typical fresh feed solids concentrations of 0.02%, 0.04% and 0.08%. The nonionic flocculant dosage ranged from 0.50 - 3.00 mg/l. Pulp pH was held in the design range of 5.8 - 6.0 units.

The weight of solids in tests performed at low feed solids concentrations is not generally sufficient to examine the effect of the compression zone on underflow solids concentration. Therefore, Tests 4, 6 and 9 were performed, at 0.25%, 0.26% and 0.35% feed solids, respectively, to predict the practical maximum underflow solids concentration for the material under test.

Test data indicate that conventional and solids contact clarifiers should be sized based upon a Rise Rate of 0.45 gpm/ft<sup>2</sup> for the production of 1.0% - 1.5% solids underflow over the range of feed solids concentrations examined.

The nonionic polymer dosage required to effect flocculation and produce clear overflow will vary with feed solids concentration. Flocculant dosage will be in the range of 1.0 - 3.0 mg/l applied at a concentration less than 0.2 g/l (0.02%) with pulp in the range of pH 6.0 units.

As illustrated in tests performed to examine practical maximum underflow solids concentration, the detention time required to achieve 1.0% - 1.5% underflow solids will be in excess of 120 minutes.

#### Ferric Hydroxide Precipitate (Ferric Sulfate Iron Source)

Static cylinder test data collected on ferric hydroxide precipitate generated using ferric sulfate as the iron source are recorded in Tables X through XVIII, and shown graphically in Figures 10 through 18, in the Appendix.

Tests were conducted at typical fresh feed solids concentrations of 0.02%, 0.04% and 0.08% with 0.375 - 0.75 mg/l nonionic flocculant. Pulp pH was held in the design range of 6.1 - 6.2 units.

As discussed above, the weight of solids in tests performed at low feed solids concentrations is not generally sufficient to examine the effect of the compression zone on underflow solids concentration. Hence, Tests 12, 15 and 18 were performed, at 0.23%, 0.43% and 0.56% feed solids, respectively, to predict the practical maximum underflow solids concentration for the material under test.

Analogous to the preceding section, test data demonstrate that sizing of conventional and solids contact clarifiers will be limited by Rise Rate.

Results indicate that a sustainable Rise Rate of 3.09 gpm/ft<sup>2</sup> will yield 2.0% - 3.0% underflow solids from 0.02% - 0.08% fresh feed solids, at pH 6.1 units. However, experience teaches that, for the application at hand, the design Rise Rate should not exceed 1.0 gpm/ft<sup>2</sup>.

The nonionic flocculant dosage will be 0.50 - 0.75 mg/l at design feed solids concentrations ranging from 0.02% - 0.08%.

As illustrated in tests performed to examine practical maximum underflow solids concentration, the detention time required to achieve 2.0% - 3.0% underflow solids will be in excess of 120 minutes.

As a result of rapid flocculation and sedimentation over the range of 0.02% - 0.08% feed solids, overflow production in a conventional clarifier will contain an estimated 50 mg/l suspended solids. However, the efficient flocculation and solids capture characteristics of a solids contact clarifier will yield clear supernatant.

## PULP RHEOLOGY

### Viscosity Tests

Pulp viscosity data collected, using a Brookfield rotating viscometer, on thickened ferric hydroxide precipitate generated using ferric chloride and ferric sulfate are recorded in the Appendix in Tables XIX - XXI and XXII - XXIII, respectively.

Tests were performed to examine the rheological behavior and relationship between apparent viscosity (cps) and shear rate (sec<sup>-1</sup>) of the above specified samples at anticipated operating temperatures and solids concentrations with pH in the design range of 6.0 units.

The apparent viscosity exhibited by a pulp at a specific shear rate can be due, in part, to solids concentration, mineralogical or chemical composition, temperature, flocculant dosage and concentration and pH.

However, the influence of pH and chemical composition on viscosity can be masked by other process conditions such as pulp solids concentration, which is typically a primary factor influencing the apparent viscosity of thickener underflow pulp.

The decreasing apparent viscosity with increasing shear rate or "shear thinning" behavior of the pulps examined is characteristic of the pseudoplastic class of non-Newtonian fluids. It demonstrates the need to achieve and maintain a specific velocity gradient or shear rate in thickener underflow lines in order to initiate and maintain flow. The shear rate required to initiate flow will increase with an increasing underflow solids concentration.

### **SUMMARY AND RECOMMENDATIONS**

Test work conducted on Hazen Research, Inc. Project No. 8316 — Arsenic Removal Project — process flow streams, as described in the above report, supports the following conclusions:

1. A medium to high molecular weight, nonionic polyacrylamide flocculant can be used to enhance the settling characteristics of ferric hydroxide precipitate generated using ferric chloride or ferric sulfate as the iron source.
2. Design of conventional and solids contact clarifiers for duty on ferric hydroxide precipitate generated using ferric chloride should be based on the following criteria:
  - a. Rise Rate of 0.45 gpm/ft<sup>2</sup> for the production of 1.0% - 1.5% solids underflow.
  - b. Fresh feed solids concentration in the range of 0.02% - 0.08%, at pH 6.0.
  - c. Nonionic flocculant dosage in the range of 1.0 - 3.0 mg/l.
  - d. Detention time required to achieve design underflow solids concentration will be in excess of 120 minutes.
  - e. Supernatant will be clear at the design Rise Rate and flocculant dosage.

3. Design of conventional and solids contact clarifiers for duty on ferric hydroxide precipitate generated using ferric sulfate should be based on the following criteria:
  - a. Rise Rate of 1.0 gpm/ft<sup>2</sup> for the production of 2.0% - 3.0% solids underflow.
  - b. Fresh feed solids concentration in the range of 0.02% - 0.08%, at pH 6.0.
  - c. Nonionic flocculant dosage in the range of 0.50 - 0.75 mg/l.
  - d. Detention time required to achieve design underflow solids concentration will be in excess of 120 minutes.
  - e. At design conditions, production of clear supernatant will require the efficient flocculation and solids capture characteristics of a solids contact clarifier.
4. Solids concentration is a primary factor influencing the apparent viscosity of thickener underflow pulps. Apparent viscosity may limit design underflow concentrations.



008579

## APPENDIX

TABLE A  
FLOCCULANT SCREENING SERIES

Hazen Research, Inc.  
Arsenic Removal Project  
Project No. 8316

Material:	Ferric Hydroxide Precipitate
Precipitation Test No.:	22
Ferric Source:	Ferric Chloride
Flocculant Sol'n:	All Solutions @ 0.05 g/l
% Solids to Test:	0.02
pH:	5.9 units
Temperature:	20 °C

Floc Added, ml	0.5	1.0	1.5	2.0	3.0	4.0	5.0
Approx. Dosage, mg/l	0.25	0.50	0.75	1.00	1.50	2.00	2.50

PRODUCT: % Chg<sub>(1)</sub>

AC 455	5	CAT	FM	MH*	H	VH	VH	VH	VH
AC 351	0	NON	M*	H	VH	VH	VH	VH	VH
AC E24	10	AN	M*	MH	H	VH	VH	VH	VH
AC 155	20	AN	M*	MH	VH	VH	VH	VH	VH
AC 1011	30	AN	M*	MH	VH	VH	VH	VH	VH
AC 156	40	AN	FM	M*	M	MH	MH	H	H

NOTES:

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight, nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

KEY TO NOTATION:

PP	Pinpoint Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
		*	Clarity Achieved.

AN	Anionic Flocculant.
NON	Nonionic Flocculant.
CAT	Cationic Flocculant.

**TABLE B**  
**FLOCCULANT SCREENING SERIES**

Hazen Research, Inc.  
Arsenic Removal Project  
Project No. 8316

Material: Ferric Hydroxide Precipitate  
Precipitation Test No.: 24  
Ferric Source: Ferric Chloride  
Flocculant Sol'n: All Solutions @ 0.05 g/l  
% Solids to Test: 0.04  
pH: 5.8 units  
Temperature: 18 °C

Floc Added, ml	0.5	1.0	1.5	2.0	3.0	4.0	5.0
Approx. Dosage, mg/l	0.25	0.50	0.75	1.00	1.50	2.00	2.50

**PRODUCT: % Chg<sub>(1)</sub>**

AC 455	5	CAT	FM	FM	FM*	M	MH	H	VH
AC 351	0	NON	FM	FM	M*	M	MH	H	VH
AC E24	10	AN	FM	FM	M*	M	MH	H	VH
AC 155	20	AN	FM	FM	M*	MH	H	H	VH
AC 1011	30	AN	FM	FM	M*	H	H	VH	VH
AC 156	40	AN	F	F	FM	FM*	M	MH	H

**NOTES:**

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight, nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

**KEY TO NOTATION:**

PP	Pinpoint Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
		*	Clarity Achieved.
AN	Anionic Flocculant.		
NON	Nonionic Flocculant.		
CAT	Cationic Flocculant.		

**TABLE C**  
**FLOCCULANT SCREENING SERIES**

Hazen Research, Inc.  
Arsenic Removal Project  
Project No. 8316

Material: Ferric Hydroxide Precipitate  
Precipitation Test No.: 26  
Ferric Source: Ferric Chloride  
Flocculant Sol'n: All Solutions @ 0.05 g/l  
% Solids to Test: 0.08  
pH: 6.0 units  
Temperature: 20 °C

Floc Added, ml	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
Approx. Dosage, mg/l	0.25	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00

**PRODUCT: % Chg<sub>(1)</sub>**

AC 455	5	CAT	VF	VF	F	FM	FM	FM	FM	M*	MH
AC 351	0	NON	F	FM	M*	M	MH	MH	H	VH	VH
AC E24	10	AN	F	FM	M*	M	M	MH	H	VH	VH
AC 155	20	AN	F	FM	M*	M	MH	H	H	VH	VH
AC 1011	30	AN	F	FM	M*	MH	MH	H	VH	VH	VH
AC 156	40	AN	—	PP	F	FM	M	M	M	H	H

**NOTES:**

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight, nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

**KEY TO NOTATION:**

PP	Pinpoint Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
		*	Clarity Achieved.
AN	Anionic Flocculant.		
NON	Nonionic Flocculant.		
CAT	Cationic Flocculant.		

**TABLE D**  
**FLOCCULANT SCREENING SERIES**

Hazen Research, Inc.  
Arsenic Removal Project  
Project No. 8316

Material: Ferric Hydroxide Precipitate  
Precipitation Test No.: 23  
Ferric Source: Ferric Sulfate  
Flocculant Sol'n: All Solutions @ 0.05 g/l  
% Solids to Test: 0.02  
pH: 6.1 units  
Temperature: 18 °C

Floc Added, ml	0.5	1.0	1.5	2.0	3.0	4.0	5.0
Approx. Dosage, mg/l	0.25	0.50	0.75	1.00	1.50	2.00	2.50

**PRODUCT: % Chg<sub>(1)</sub>**

AC 455	5	CAT	—	F	M*	MH	H	VH	VH
AC 351	0	NON	F	M*	H	VH	VH	VH	VH
AC E24	10	AN	F	M*	H	VH	VH	VH	VH
AC 155	20	AN	H*	VH	VH	VH	VH	VH	VH
AC 1011	30	AN	H*	VH	VH	VH	VH	VH	VH
AC 156	40	AN	VF	FM	M*	MH	H	VH	VH

**NOTES:**

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight, nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

**KEY TO NOTATION:**

PP	Pinpoint Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
		*	Clarity Achieved.
AN	Anionic Flocculant.		
NON	Nonionic Flocculant.		
CAT	Cationic Flocculant.		

TABLE E  
FLOCCULANT SCREENING SERIES

Hazen Research, Inc.  
Arsenic Removal Project  
Project No. 8316

Material: Ferric Hydroxide Precipitate  
Precipitation Test No.: 25  
Ferric Source: Ferric Sulfate  
Flocculant Sol'n: All Solutions @ 0.05 g/l  
% Solids to Test: 0.04  
pH: 6.2 units  
Temperature: 20 °C

Floc Added, ml	0.5	1.0	1.5	2.0	3.0	4.0	5.0
Approx. Dosage, mg/l	0.25	0.50	0.75	1.00	1.50	2.00	2.50

PRODUCT: % Chg<sub>(1)</sub>

AC 455	5	CAT	F	M*	MH	H	VH	VH	VH
AC 351	0	NON	F	M*	H	VH	VH	VH	VH
AC E24	10	AN	F	M*	H	VH	VH	VH	VH
AC 155	20	AN	FM	MH*	VH	VH	VH	VH	VH
AC 1011	30	AN	FM	H*	VH	VH	VH	VH	VH
AC 156	40	AN	VF	F	M*	MH	H	H	VH

NOTES:

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight, nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

KEY TO NOTATION:

PP	Pinpoint Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
		*	Clarity Achieved.
AN	Anionic Flocculant.		
NON	Nonionic Flocculant.		
CAT	Cationic Flocculant.		

**TABLE F**  
**FLOCCULANT SCREENING SERIES**

Hazen Research, Inc.  
Arsenic Removal Project  
Project No. 8316

Material:	Ferric Hydroxide Precipitate
Precipitation Test No.:	27
Ferric Source:	Ferric Sulfate
Flocculant Sol'n:	All Solutions @ 0.05 g/l
% Solids to Test:	0.08
pH:	6.2 units
Temperature:	18 °C
Floc Added, ml	0.5    1.0    1.5    2.0    3.0    4.0    5.0
Approx. Dosage, mg/l	0.25   0.50   0.75   1.00   1.50   2.00   2.50

**PRODUCT: % Chg<sub>(1)</sub>**

AC 455	5	CAT	F	FM	M*	MH	H	VH	VH
AC 351	0	NON	FM	MH*	H	VH	VH	VH	VH
AC E24	10	AN	FM	M*	H	VH	VH	VH	VH
AC 155	20	AN	FM	M*	H	VH	VH	VH	VH
AC 1011	30	AN	FM	MH*	H	VH	VH	VH	VH
AC 156	40	AN	VF	F	FM	M*	MH	H	H

**NOTES:**

Product chosen for performance was Allied Colloids Percol 351, a medium to high molecular weight, nonionic polyacrylamide. Other products meeting the same description would also serve.

(1) All products were polyacrylamides, % charge density indicated.

**KEY TO NOTATION:**

PP	Pinpoint Structure.	M	Medium Structure.
VF	Very Fine Structure.	MH	Medium to Heavy Structure.
F	Fine Structure.	H	Heavy Structure.
FM	Fine to Medium Structure.	VH	Very Heavy Structure.
		*	Clarity Achieved.
AN	Anionic Flocculant.		
NON	Nonionic Flocculant.		
CAT	Cationic Flocculant.		

**TABLE G**  
**STATIC THICKENING DATA SUMMARY**

Hazen Research, Inc.  
Arsenic Removal Project  
Project No. 8316

TEST NO.	FEED % D.S./pH	MAT'L <sub>(1)</sub>	FLOC <sub>(2)</sub> mg/l	H.L. <sub>(3)</sub>	UNIT AREA <sub>(4)</sub> ft <sup>2</sup> /STPD @ UF		
					1.0%	1.5%	2.0%
1	0.02/5.9	OH-Cl-22	0.50	2.22	556.5	578.6	589.6
2	0.02/5.9	OH-Cl-22	0.75	2.36	524.8	548.6	560.4
3	0.02/5.9	OH-Cl-22	1.00	2.59	476.9	498.7	509.7
4	0.25/6.0	OH-Cl-22	1.25	0.23	288.4	383.1	430.5
5	0.04/5.8	OH-Cl-24	1.50	1.20	789.1	823.9	841.3
6	0.26/5.8	OH-Cl-24	2.50	0.16	489.3	597.0	650.8
7	0.08/6.0	OH-Cl-26	2.25	0.45	1,113.6	1,211.8	1,260.9
8	0.08/6.0	OH-Cl-26	3.00	0.60	1,054.7	1,155.9	1,206.5
9	0.35/6.0	OH-Cl-26	5.00	0.15	372.5	512.7	582.7
					2.0%	2.5%	3.0%
10	0.02/6.1	OH-SO <sub>4</sub> -23	0.50	2.29	366.9	371.8	375.0
11	0.02/6.1	OH-SO <sub>4</sub> -23	0.75	2.57	364.4	369.8	373.4
12	0.23/6.1	OH-SO <sub>4</sub> -23	1.25	1.14	252.9	281.7	300.9
13	0.04/6.2	OH-SO <sub>4</sub> -25	0.50	2.71	202.6	206.2	208.5
14	0.04/6.2	OH-SO <sub>4</sub> -25	0.75	3.09	186.3	190.0	192.5
15	0.43/6.2	OH-SO <sub>4</sub> -25	1.25	0.22	233.1	264.5	285.5
16	0.08/6.2	OH-SO <sub>4</sub> -27	0.375	1.86	156.6	161.1	164.0
17	0.08/6.2	OH-SO <sub>4</sub> -27	0.50	2.43	119.5	123.2	125.6
18	0.56/6.2	OH-SO <sub>4</sub> -27	0.75	0.22	134.4	166.5	187.8

**NOTES:**

- (1) OH-Cl-XX: Ferric Hydroxide Precipitate — Ferric Chloride as Ferric Source — Precipitation Test Number.  
OH-SO<sub>4</sub>-XX: Ferric Hydroxide Precipitate — Ferric Sulfate as Ferric Source — Precipitation Test Number.
- (2) FLOC: Percol 351, a medium to high molecular weight, nonionic polyacrylamide was used for all tests. Other products meeting the same description would also serve.
- (3) Hydraulic Loading or Rise Rate (gpm/ft<sup>2</sup>) includes a 0.5 scale-up factor.
- (4) Unit Area (ft<sup>2</sup>/STPD) includes a 1.25 scale-up factor.



**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008587

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: I  
Test No.: 1  
Test Date: May 9, 1994  
By: ST  
Location: HRI

Material: 0.02 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 22)  
99.98 % Liquid Consisting of Treated Water

**Object of Test:** To Determine Settling Characteristics at Conditions Noted.

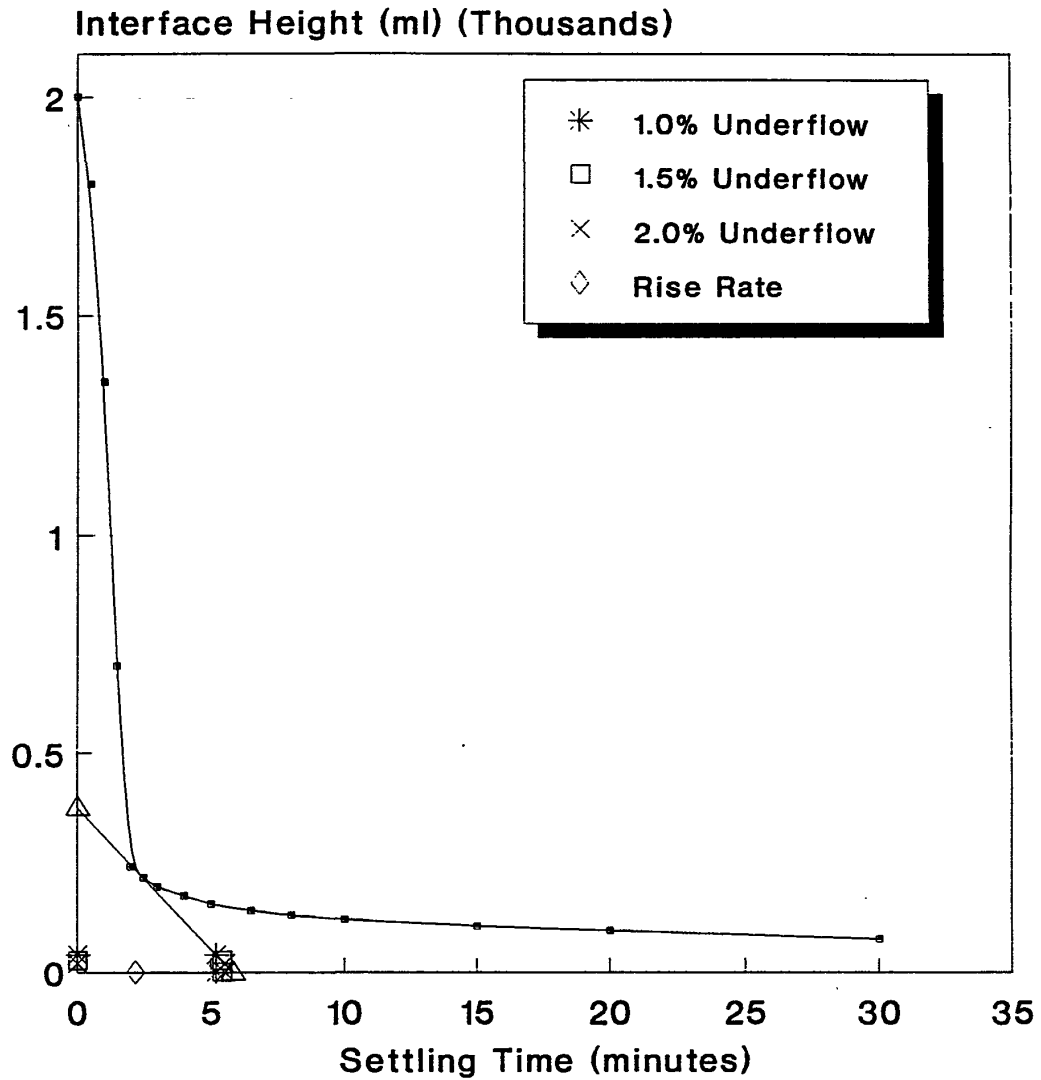
pH:	5.9 Units	<b>SETTLING DATA</b>		
Temperature:	20 °C		Interface	Average
Floc. Dosage:	0.5 mg/l	Time	Height	Percent
Ferric Source:	Ferric Chloride	(min)	(mls)	Solids
<b>Flocculant:</b>	Percol 351	0	2000	0.02
Type:	Nonionic	0.5	1800	0.02
Concentration:	0.05 g/l	1	1350	0.03
Mls Added:	20 mls	1.5	700	0.06
Picket Speed:	6 rph	2	240	0.17
		2.5	215	0.19
<b>Description:</b>	Clear Supernatant;	3	195	0.20
	Heavy Floc. Structure.	4	175	0.23
		5	155	0.26
<b>Underflow Measurements:</b>		6.5	140	0.28
Undecanted Volume:	2000 mls	8	130	0.31
Slurry & Tare:	3107.4 gms	10	120	0.33
Cylinder Weight:	1107.0 gms	15	105	0.38
Slurry Weight:	2000.4 gms	20	95	0.42
Dry Solids Weight:	0.4 gms	30	75	0.53
Supernatant S.G.	3.2			
Solids S.G.	1.0			
<b>Settling Vessel Size:</b>	1540 mls/ft			
	5052 mls/m			
Ho=	1.30 ft	0.396 m)		
Co=	6.24E-06 ST/ft³	2.00E-04 MT/m³)		
Tu =	3.61E-03 days at	1.0 % u'flow		
Tu =	3.75E-03 days at	1.5 % u'flow		
Tu =	3.82E-03 days at	2.0 % u'flow		
<b>Unit Area at</b>	1.0 % u'flow=	556.53 ft²/STPD	(	56.993 m²/MTPD)
<b>Unit Area at</b>	1.5 % u'flow=	578.59 ft²/STPD	(	59.253 m²/MTPD)
<b>Unit Area at</b>	2.0 % u'flow=	589.63 ft²/STPD	(	60.382 m²/MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

**Rise Rate =** 2.22 gpm/ft² ( 5.422 m³/(hr·m²))  
Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 1: INTERFACE HT. vs. SETTLING TIME**

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.02%; pH: 5.9 Units  
Floc. Dosage: 0.5 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008589

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: II  
Test No.: 2  
Test Date: May 9, 1994  
By: ST  
Location: HRI

Material: 0.02 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 22)  
99.98 % Liquid Consisting of Treated Water

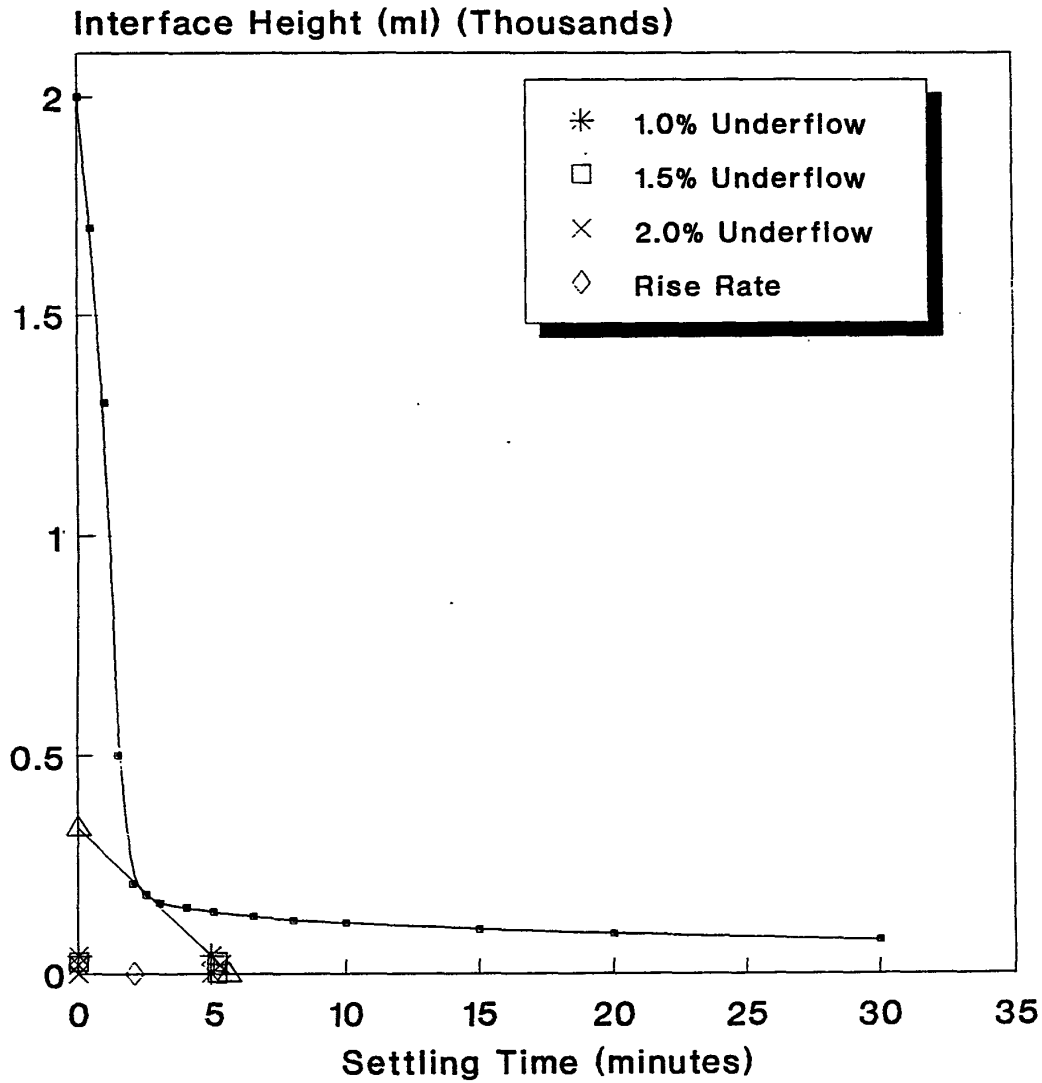
Object of Test: To Determine Settling Characteristics at Conditions Noted.

pH: 5.9 Units		<b>SETTLING DATA</b>		
Temperature: 20 °C			Interface	Average
Floc. Dosage: 0.75 mg/l		Time	Height	Percent
Ferric Source: Ferric Chloride		(min)	(mls)	Solids
<b>Flocculant:</b> Percol 351		0	2000	0.02
Type: Nonionic		0.5	1700	0.02
Concentration: 0.05 g/l		1	1300	0.03
Mls Added: 30 mls		1.5	500	0.08
Picket Speed: 6 rph		2	205	0.19
		2.5	180	0.22
<b>Description:</b> Clear Supernatant;		3	160	0.25
Heavy Floc. Structure.		4	150	0.27
		5	140	0.28
<b>Underflow Measurements:</b>		6.5	130	0.31
Undecanted Volume: 2000 mls		8	120	0.33
Slurry & Tare: 3090.4 gms		10	115	0.35
Cylinder Weight: 1090.0 gms		15	100	0.40
Slurry Weight: 2000.4 gms		20	90	0.44
Dry Solids Weight: 0.4 gms		30	75	0.53
Supernatant S.G. 3.2				
Solids S.G. 1.0				
<b>Settling Vessel Size:</b>		1540 mls/ft		
		5052 mls/m		
Ho=	1.30 ft	0.396 m)		
Co=	6.24E-06 ST/ft <sup>3</sup>	2.00E-04 MT/m <sup>3</sup> )		
Tu =	3.40E-03 days at	1.0 % u'flow		
Tu =	3.56E-03 days at	1.5 % u'flow		
Tu =	3.63E-03 days at	2.0 % u'flow		
Unit Area at	1.0 % u'flow=	524.84 ft <sup>2</sup> /STPD	(	53.748 m <sup>2</sup> /MTPD)
Unit Area at	1.5 % u'flow=	548.56 ft <sup>2</sup> /STPD	(	56.177 m <sup>2</sup> /MTPD)
Unit Area at	2.0 % u'flow=	560.42 ft <sup>2</sup> /STPD	(	57.392 m <sup>2</sup> /MTPD)
Note: Unit Area Includes a 1.25 Scale-Up Factor.				

Rise Rate = 2.36 gpm/ft<sup>2</sup> ( 5.764 m<sup>3</sup>/(hr\*m<sup>2</sup>))  
Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 2: INTERFACE HT. vs. SETTLING TIME**

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.02%; pH: 5.9 Units  
Floc. Dosage: 0.75 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: III  
Test No.: 3  
Test Date: May 9, 1994  
By: ST  
Location: HRI

008591

Material: 0.02 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 22)  
99.98 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

pH:	5.9 Units	<b>SETTLING DATA</b>		
Temperature:	20 °C		Interface	Average
Floc. Dosage:	1.0 mg/l		Height	Percent
Ferric Source:	Ferric Chloride	Time (min)	(mls)	Solids
<b>Flocculant:</b>	Percol 351	0	2000	0.02
Type:	Nonionic	0.5	1650	0.02
Concentration:	0.05 g/l	1	1303	0.03
Mls Added:	40 mls	1.5	225	0.18
Picket Speed:	6 rph	2	200	0.20
		2.5	180	0.22
<b>Description:</b>	Clear Supernatant;	3	165	0.24
	Very Heavy Floc. Structure.	4	150	0.27
		5	135	0.30
<b>Underflow Measurements:</b>		6.5	120	0.33
Undecanted Volume:	2000 mls	8	110	0.36
Slurry & Tare:	3090.4 gms	10	100	0.40
Cylinder Weight:	1090.0 gms	15	95	0.42
Slurry Weight:	2000.4 gms	20	90	0.44
Dry Solids Weight:	0.4 gms	30	80	0.50
Supernatant S.G.	3.2			
Solids S.G.	1.0			
<b>Settling Vessel Size:</b>	1540 mls/ft			
	5052 mls/m			
Ho=	1.30 ft	0.396 m)		
Co=	6.24E-06 ST/ft <sup>3</sup>	2.00E-04 MT/m <sup>3</sup> )		
Tu =	3.09E-03 days at	1.0 % u'flow		
Tu =	3.23E-03 days at	1.5 % u'flow		
Tu =	3.31E-03 days at	2.0 % u'flow		
<b>Unit Area at</b>	1.0 % u'flow=	476.91 ft <sup>2</sup> /STPD	(	48.839 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	1.5 % u'flow=	498.74 ft <sup>2</sup> /STPD	(	51.075 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	2.0 % u'flow=	509.66 ft <sup>2</sup> /STPD	(	52.193 m <sup>2</sup> /MTPD)

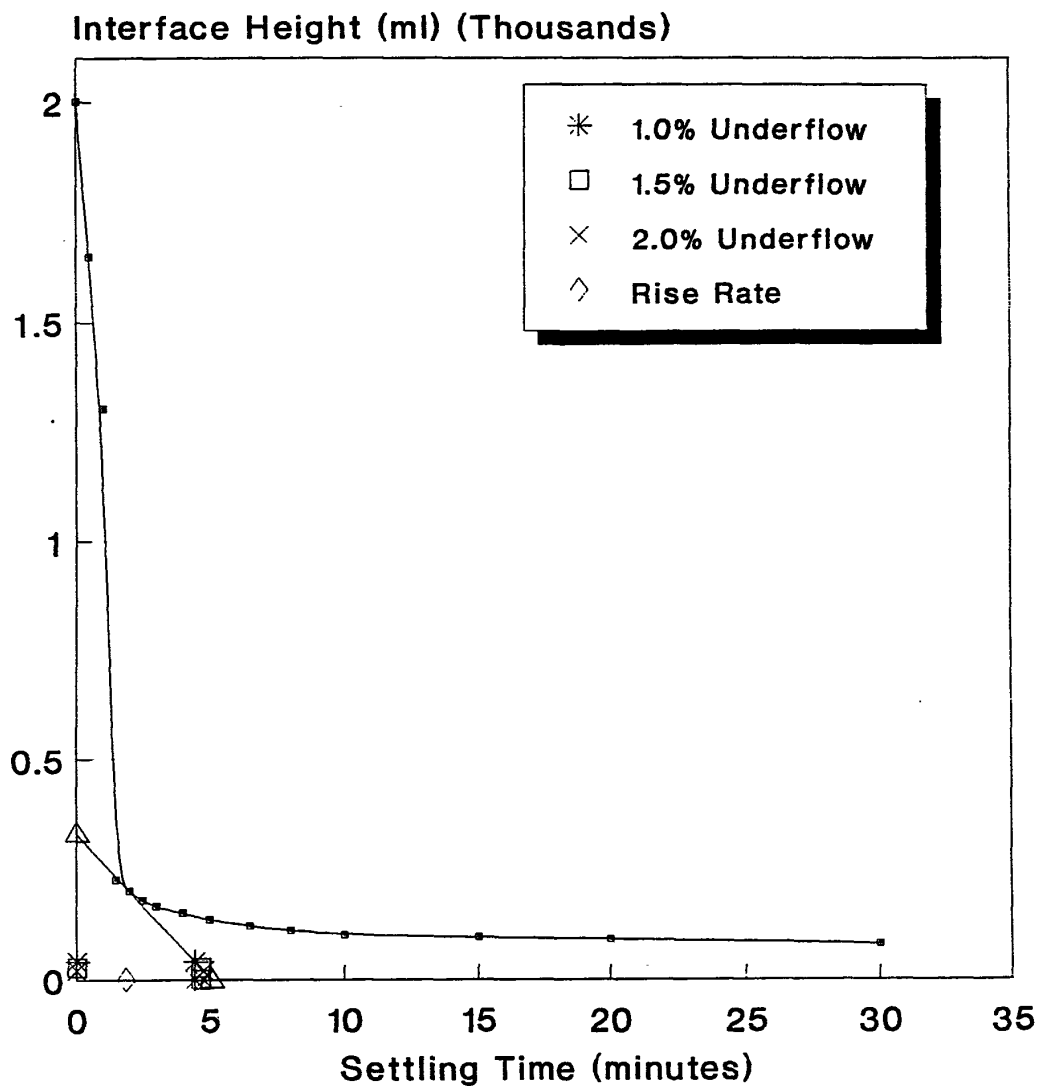
Note: Unit Area Includes a 1.25 Scale-Up Factor.

**Rise Rate =** 2.59 gpm/ft<sup>2</sup> ( 6.332 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 3: INTERFACE HT. vs. SETTLING TIME**

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.02%; pH: 5.9 Units  
Floc. Dosage: 1.0 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008593

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: IV  
Test No.: 4  
Test Date: May 9, 1981  
By: ST  
Location: HRI

Material: 0.25 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 22)  
99.75 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

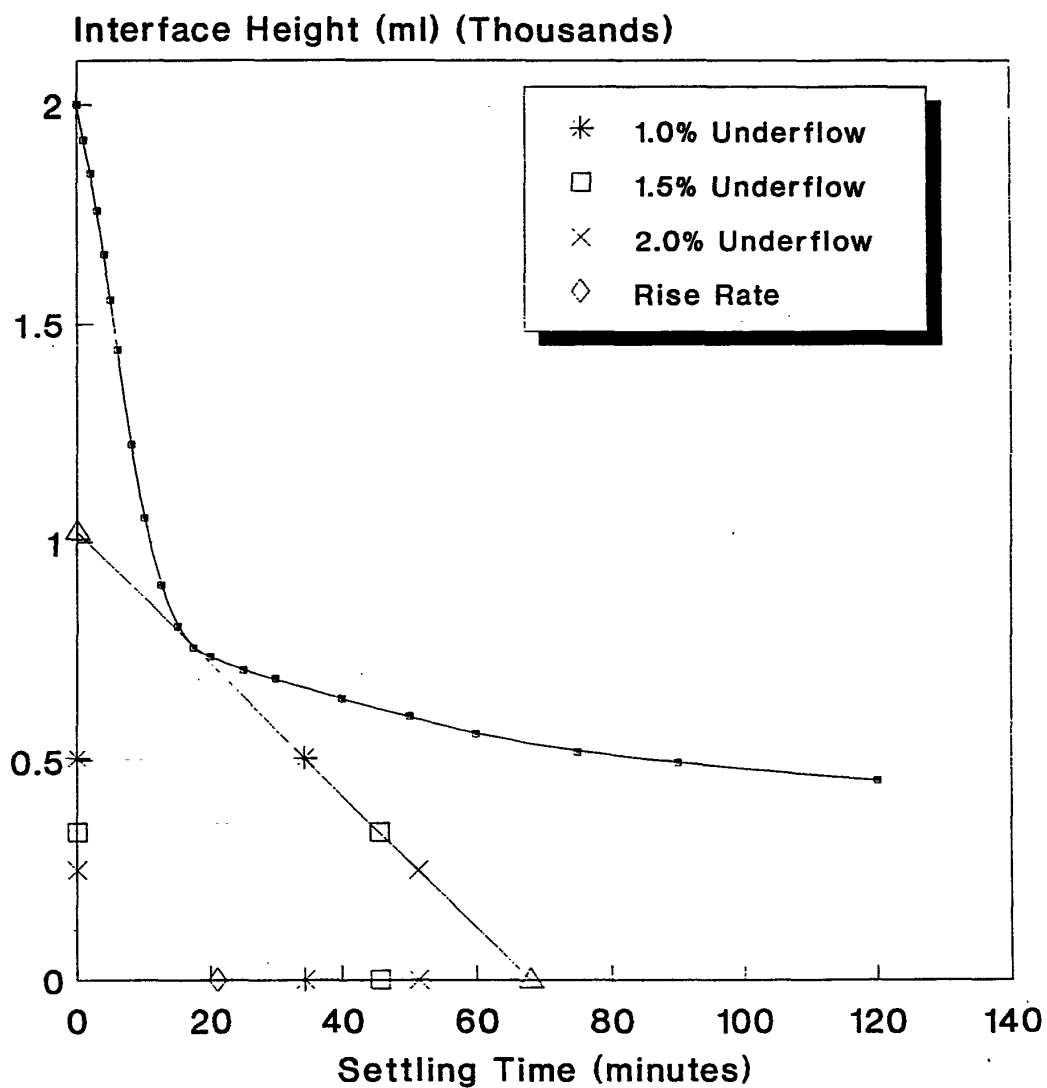
		SETTLING DATA		
		Time	Interface	Average
		(min)	Height	Percent
			(mls)	Solids
pH:	6.0 Units			
Temperature:	20 °C			
Floc. Dosage:	1.25 mg/l			
Ferric Source:	Ferric Chloride			
<b>Flocculant:</b>	Percol 351	0	2000	0.25
Type:	Nonionic	1	1920	0.26
Concentration:	0.05 g/l	2	1845	0.28
Mls Added:	50 mls	3	1760	0.29
Picket Speed:	6 rph	4	1660	0.31
		5	1555	0.33
<b>Description:</b>	Clear Supernatant;	6	1440	0.35
	Heavy Floc. Structure.	8	1225	0.41
		10	1055	0.48
<b>Underflow Measurements:</b>		12.5	900	0.56
Undecanted Volume:	2000 mls	15	805	0.63
Slurry & Tare:	3095.1 gms	17.5	755	0.67
Cylinder Weight:	1090.0 gms	20	735	0.69
Slurry Weight:	2005.1 gms	25	705	0.72
Dry Solids Weight:	5.1 gms	30	685	0.74
Supernatant S.G.	3.2	40	640	0.79
Solids S.G.	1.0	50	600	0.84
		60	560	0.90
<b>Settling Vessel Size:</b>	1540 mls/ft	75	520	0.97
	5052 mls/m	90	495	1.02
Ho=	1.30 ft	120	455	1.11
Co=	7.96E-05 ST/ft <sup>3</sup>			
	0.396 m)			
Tu =	2.38E-02 days at			1.0 % u'flow
Tu =	3.17E-02 days at			1.5 % u'flow
Tu =	3.56E-02 days at			2.0 % u'flow
<b>Unit Area at</b>	1.0 % u'flow=	288.39 ft <sup>2</sup> /STPD	(	29.534 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	1.5 % u'flow=	383.13 ft <sup>2</sup> /STPD	(	39.236 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	2.0 % u'flow=	430.50 ft <sup>2</sup> /STPD	(	44.087 m <sup>2</sup> /MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 0.23 gpm/ft<sup>2</sup> ( 0.565 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 4: INTERFACE HT. vs. SETTLING TIME**  
**Hazen Research, Inc.**  
**Arsenic Removal Project**



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.25%; pH: 6.0 Units  
Floc. Dosage: 1.25 mg/l



**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: V  
Test No.: 5  
Test Date: May 10, 199  
By: ST  
Location: HRI

008595

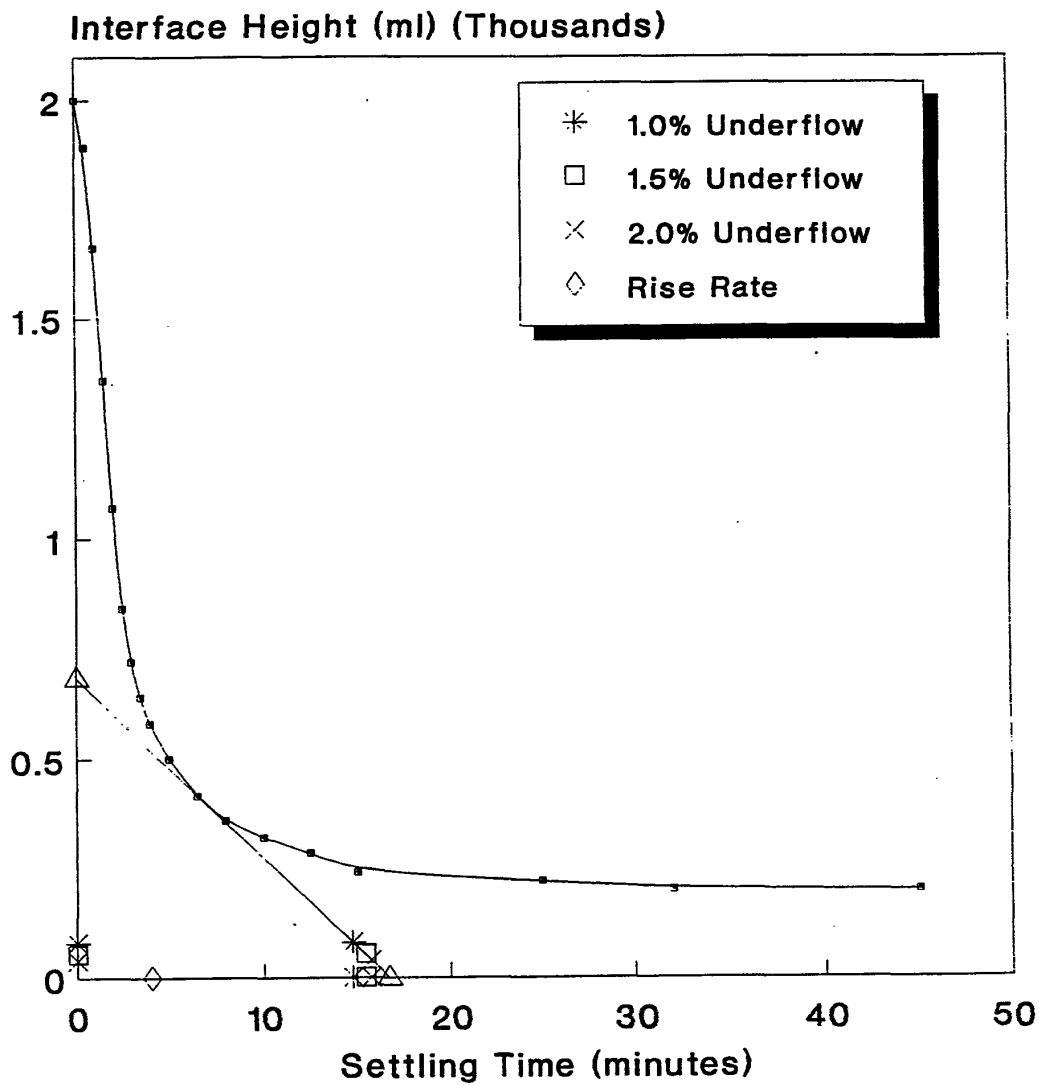
Material: 0.04 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 24)  
99.96 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

pH:	5.8 Units	<b>SETTLING DATA</b>		
Temperature:	18 °C		Interface	Average
Floc. Dosage:	1.5 mg/l	Time	Height	Percent
Ferric Source:	Ferric Chloride	(min)	(mls)	Solids
<b>Flocculant:</b>	Percol 351	0	2000	0.04
Type:	Nonionic	0.5	1890	0.04
Concentration:	0.1 g/l	1	1660	0.05
Mls Added:	30 mls	1.5	1360	0.06
Picket Speed:	6 rph	2	1070	0.07
		2.5	840	0.10
<b>Description:</b>	Clear Supernatant;	3	720	0.11
	Heavy Floc. Structure.	3.5	640	0.12
		4	580	0.14
<b>Underflow Measurements:</b>		5	500	0.16
Undecanted Volume:	2000 mls	6.5	415	0.19
Slurry & Tare:	3090.8 gms	8	360	0.22
Cylinder Weight:	1090.0 gms	10	320	0.25
Slurry Weight:	2000.8 gms	12.5	285	0.28
Dry Solids Weight:	0.8 gms	15	240	0.33
Supernatant S.G.	3.2	25	220	0.36
Solids S.G.	1.0	32	200	0.40
		45	200	0.40
<b>Settling Vessel Size:</b>	1540 mls/ft			
	5052 mls/m			
Ho=	1.30 ft	0.396 m)		
Co=	1.25E-05 ST/ft³	4.00E-04 MT/m³)		
Tu =	1.02E-02 days at	1.0 % u'flow		
Tu =	1.07E-02 days at	1.5 % u'flow		
Tu =	1.09E-02 days at	2.0 % u'flow		
Unit Area at	1.0 % u'flow=	789.10 ft²/STPD	(	80.811 m²/MTPD)
Unit Area at	1.5 % u'flow=	823.89 ft²/STPD	(	84.373 m²/MTPD)
Unit Area at	2.0 % u'flow=	841.28 ft²/STPD	(	86.154 m²/MTPD)
Note: Unit Area Includes a 1.25 Scale-Up Factor.				

Rise Rate = 1.20 gpm/ft² ( 2.932 m³/(hr\*m²))  
Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 5: INTERFACE HT. vs. SETTLING TIME**  
Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.04%; pH: 5.8 Units  
Floc. Dosage: 1.5 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: VI  
Test No.: 6  
Test Date: May 10, 199  
By: ST  
Location: HRI

008597

Material: 0.26 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 24)  
99.74 % Liquid Consisting of Treated Water

**Object of Test:** To Determine Settling Characteristics at Conditions Noted.

pH:	5.8 Units	<b>SETTLING DATA</b>		
Temperature:	18 °C		Interface	Average
Floc. Dosage:	2.5 mg/l	Time	Height	Percent
Ferric Source:	Ferric Chloride	(min)	(mls)	Solids
<b>Flocculant:</b>	Percol 351	0	2000	0.26
Type:	Nonionic	1	1990	0.26
Concentration:	0.1 g/l	2	1945	0.27
Mls Added:	50 mls	3	1885	0.28
Picket Speed:	6 rph	4	1830	0.28
		5	1740	0.30
<b>Description:</b>	Clear Supernatant;	6	1660	0.31
	Heavy Floc. Structure.	8	1550	0.33
		10	1405	0.37
<b>Underflow Measurements:</b>		12.5	1280	0.40
Undecanted Volume:	2000 mls	15	1180	0.44
Slurry & Tare:	3095.2 gms	20	1055	0.49
Cylinder Weight:	1090.0 gms	25	965	0.54
Slurry Weight:	2005.2 gms	30	905	0.57
Dry Solids Weight:	5.2 gms	40	825	0.63
Supernatant S.G.	3.2	50	770	0.67
Solids S.G.	1.0	60	735	0.70
		75	690	0.75
<b>Settling Vessel Size:</b>	1540 mls/ft	90	660	0.78
	5052 mls/m	120	600	0.86
Ho=	1.30 ft			
Co=	8.12E-05 ST/ft³			
	0.396 m)			
Tu =	4.13E-02 days at			1.0 % u'flow
Tu =	5.03E-02 days at			1.5 % u'flow
Tu =	5.49E-02 days at			2.0 % u'flow

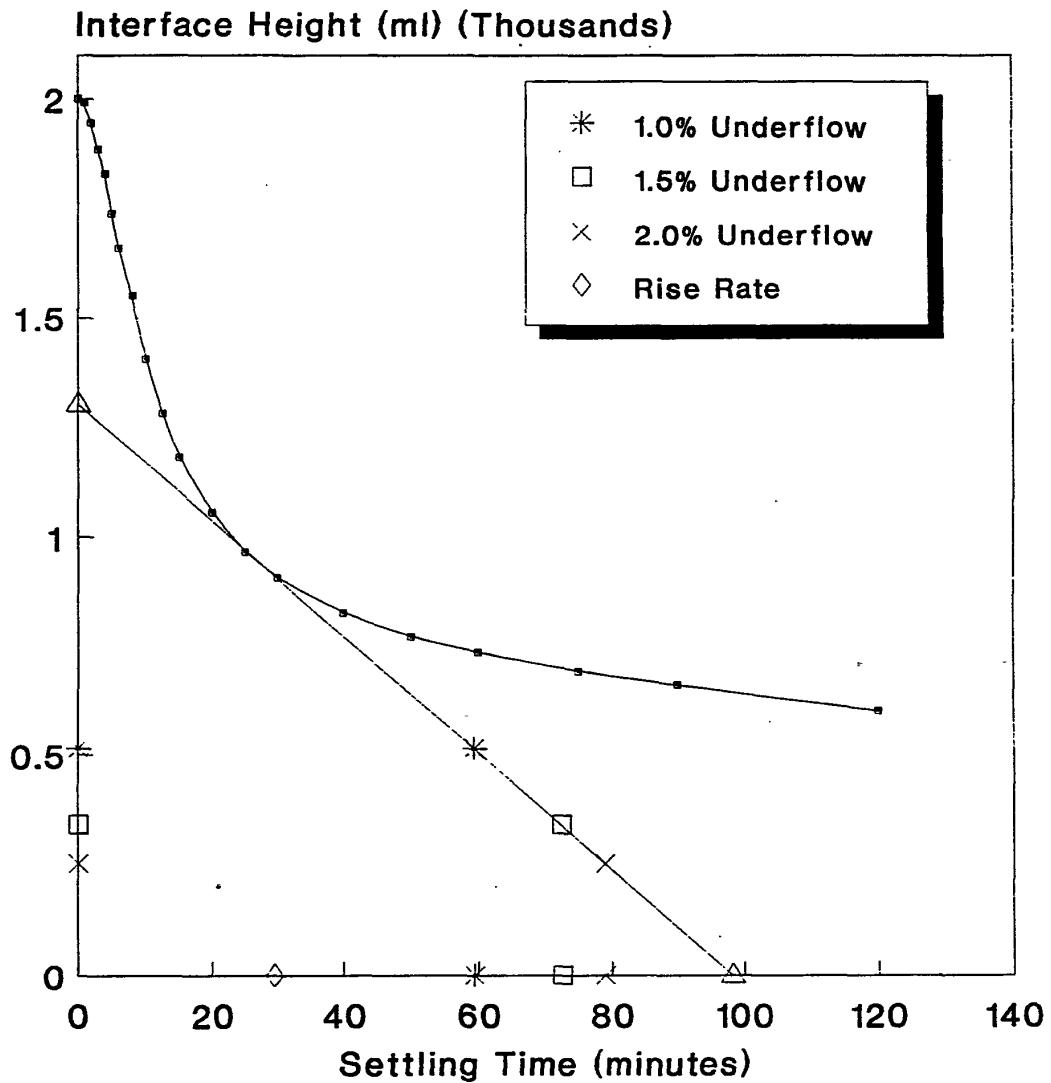
**Unit Area at** 1.0 % u'flow= 489.29 ft²/STPD ( 50.107 m²/MTPD)  
**Unit Area at** 1.5 % u'flow= 597.00 ft²/STPD ( 61.137 m²/MTPD)  
**Unit Area at** 2.0 % u'flow= 650.85 ft²/STPD ( 66.652 m²/MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

**Rise Rate =** 0.16 gpm/ft² ( 0.402 m³/(hr\*m²))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 6: INTERFACE HT. vs. SETTLING TIME**  
**Hazen Research, Inc.**  
**Arsenic Removal Project**



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.26%; pH: 5.8 Units  
Floc. Dosage: 2.5 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: VII  
Test No.: 7  
Test Date: May 11, 1  
By: ST  
Location: HRI

008599

Material: 0.08 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 26)  
99.92 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

		SETTLING DATA		
		Time	Interface	Average
		(min)	Height	Percent
			(mls)	Solids
pH:	6.0 Units			
Temperature:	20 °C			
Floc. Dosage:	2.25 mg/l			
Ferric Source:	Ferric Chloride			
<b>Flocculant:</b>	Percol 351	0	2000	0.08
Type:	Nonionic	0.5	1930	0.08
Concentration:	0.1 g/l	1	1845	0.09
MLs Added:	45 mls	1.5	1760	0.09
Picket Speed:	6 rph	2	1655	0.10
		2.5	1550	0.10
<b>Description:</b>	Clear Supernatant;	3	1450	0.11
	Heavy Floc. Structure.	3.5	1360	0.12
		4	1280	0.12
<b>Underflow Measurements:</b>		4.5	1200	0.13
Undecanted Volume:	2000 mls	5	1125	0.14
Slurry & Tare:	3091.6 gms	6.5	940	0.17
Cylinder Weight:	1090.0 gms	8	820	0.19
Slurry Weight:	2001.6 gms	10	715	0.22
Dry Solids Weight:	1.6 gms	12.5	620	0.26
Supernatant S.G.	3.2	15	555	0.29
Solids S.G.	1.0	20	460	0.35
		25	420	0.38
<b>Settling Vessel Size:</b>	1540 mls/ft	30	385	0.41
	5052 mls/m	40	360	0.44
Ho=	1.30 ft	50	340	0.47
Co=	2.50E-05 ST/ft <sup>3</sup>	60	320	0.50
		75	305	0.52
Tu =	2.89E-02 days at	90	285	0.56
	1.0 % u'flow	120	275	0.58
Tu =	3.14E-02 days at			
	1.5 % u'flow			
Tu =	3.27E-02 days at			
	2.0 % u'flow			
Unit Area at	1.0 % u'flow=	1113.60 ft <sup>2</sup> /STPD	(	114.042 m <sup>2</sup> /MTPD)
Unit Area at	1.5 % u'flow=	1211.80 ft <sup>2</sup> /STPD	(	124.098 m <sup>2</sup> /MTPD)
Unit Area at	2.0 % u'flow=	1260.90 ft <sup>2</sup> /STPD	(	129.127 m <sup>2</sup> /MTPD)

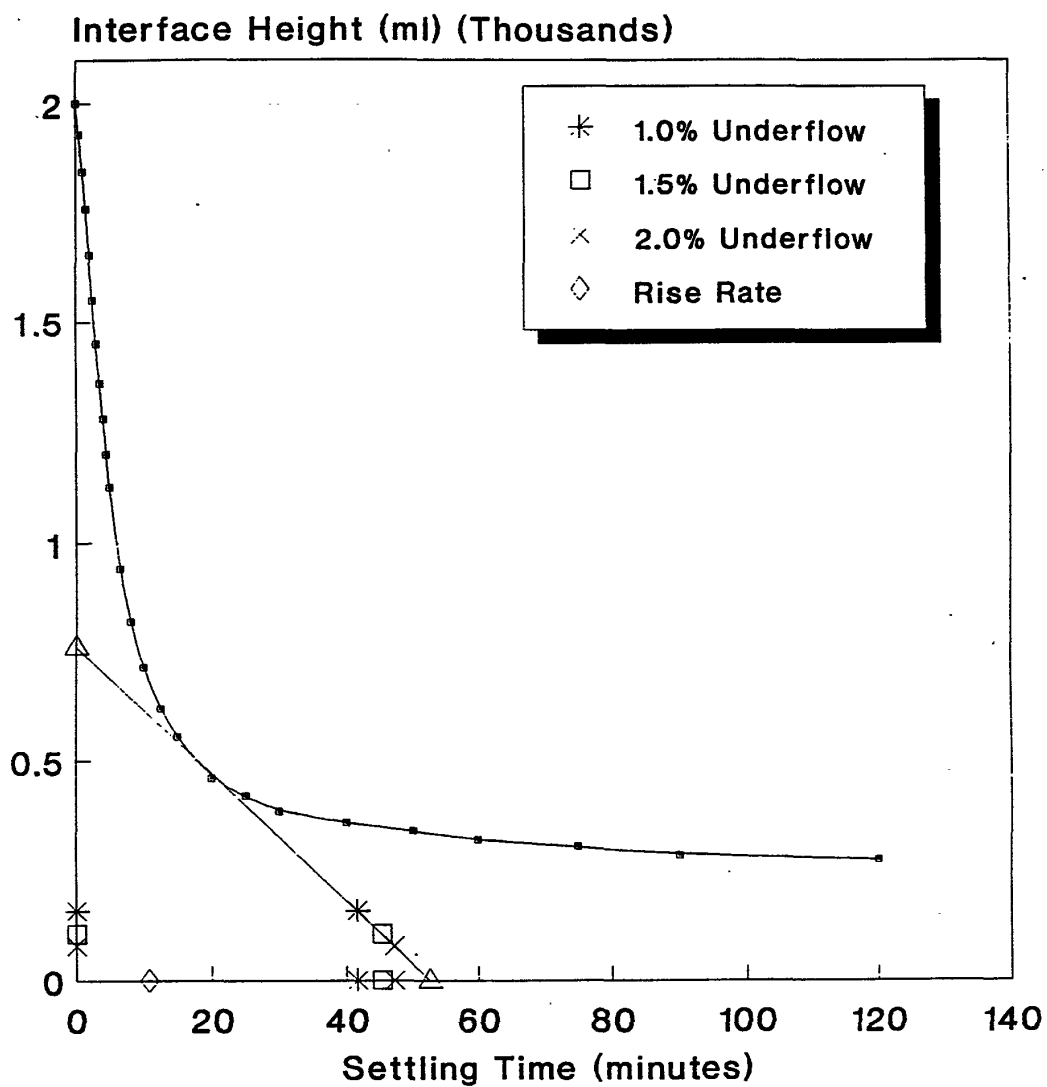
Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 0.45 gpm/ft<sup>2</sup> ( 1.104 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 7: INTERFACE HT. vs. SETTLING TIME**

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.08%; pH: 6.0 Units  
Floc. Dosage: 2.25 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008601

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: VIII  
Test No.: 8  
Test Date: May 11, 1981  
By: ST  
Location: HRI

Material: 0.08 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 26)  
99.92 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

		SETTLING DATA		
		Time	Interface	Average
		(min)	Height	Percent
			(mls)	Solids
pH:	6.0 Units			
Temperature:	20 °C			
Floc. Dosage:	3.0 mg/l			
Ferric Source:	Ferric Chloride			
<b>Flocculant:</b>	Percol 351	0	2000	0.08
<b>Type:</b>	Nonionic	0.5	1900	0.08
<b>Concentration:</b>	0.1 g/l	1	1785	0.09
<b>Ms Added:</b>	60 mls	1.5	1680	0.10
<b>Picket Speed:</b>	6 rph	2	1540	0.10
		2.5	1415	0.11
<b>Description:</b>	Clear Supernatant;	3	1275	0.13
	Heavy Floc. Structure.	4	1080	0.15
		5	950	0.17
<b>Underflow Measurements:</b>		6	840	0.19
Undecanted Volume:	2000 mls	7	760	0.21
Slurry & Tare:	3108.6 gms	8	700	0.23
Cylinder Weight:	1107.0 gms	10	615	0.26
Slurry Weight:	2001.6 gms	12.5	540	0.30
Dry Solids Weight:	1.6 gms	15	495	0.32
Supernatant S.G.	3.2	20	440	0.36
Solids S.G.	1.0	25	410	0.39
		30	385	0.41
<b>Settling Vessel Size:</b>	1540 mls/ft	40	370	0.43
	5052 mls/m	50	355	0.45
Ho=	1.30 ft	60	335	0.48
Co=	2.50E-05 ST/ft <sup>3</sup>	75	310	0.51
		90	295	0.54
Tu =	2.74E-02 days at	120	270	0.59
	1.0 % u'flow			
Tu =	3.00E-02 days at			
	1.5 % u'flow			
Tu =	3.13E-02 days at			
	2.0 % u'flow			
<b>Unit Area at</b>	1.0 % u'flow=	1054.68 ft <sup>2</sup> /STPD	(	108.008 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	1.5 % u'flow=	1155.87 ft <sup>2</sup> /STPD	(	118.370 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	2.0 % u'flow=	1206.46 ft <sup>2</sup> /STPD	(	123.551 m <sup>2</sup> /MTPD)

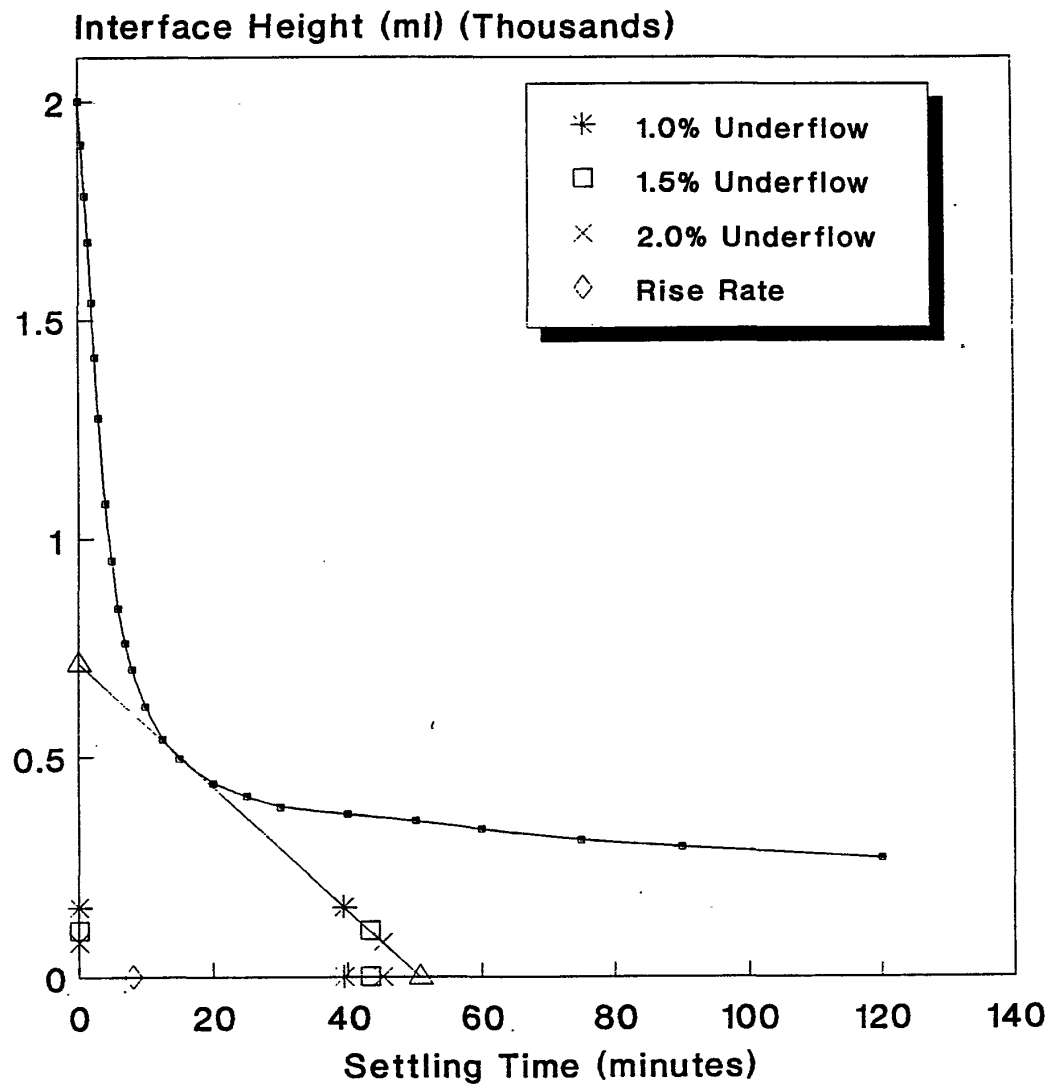
Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 0.60 gpm/ft<sup>2</sup> ( 1.466 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 8: INTERFACE HT. vs. SETTLING TIME**

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.08%; pH: 6.0 Units  
Floc. Dosage: 3.0 mg/l



**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008603

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: IX  
Test No.: 9  
Test Date: May 11, 199  
By: ST  
Location: HRI

Material: 0.35 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 26)  
99.65 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

pH:	6.0 Units	<b>SETTLING DATA</b>		
Temperature:	20 °C		Interface	Average
Floc. Dosage:	5.0 mg/l	Time	Height	Percent
Ferric Source:	Ferric Chloride	(min)	(mls)	Solids
<b>Flocculant:</b>	Percol 351	0	2000	0.35
Type:	Nonionic	1	1960	0.36
Concentration:	0.1 g/l	2	1905	0.37
Mls Added:	100 mls	3	1855	0.38
Picket Speed:	6 rph	4	1790	0.39
		5	1720	0.41
<b>Description:</b>	Clear Supernatant;	6	1655	0.42
	Medium to Heavy Floc. Structure.	7	1600	0.44
		8.5	1500	0.46
<b>Underflow Measurements:</b>		10	1415	0.49
Undecanted Volume:	2000 mls	12.5	1300	0.54
Slurry & Tare:	3114.0 gms	15	1215	0.57
Cylinder Weight:	1107.0 gms	20	1120	0.62
Slurry Weight:	2007.0 gms	25	1055	0.66
Dry Solids Weight:	7.0 gms	30	1005	0.69
Supernatant S.G.	3.2	40	940	0.74
Solids S.G.	1.0	50	905	0.77
		60	865	0.80
<b>Settling Vessel Size:</b>	1540 mls/ft	75	830	0.84
	5052 mls/m	90	795	0.87
Ho=	1.30 ft	120	745	0.93
Co=	1.09E-04 ST/ft <sup>3</sup>	150	700	0.99
		180	665	1.04
Tu =	4.23E-02 days at	1.0 % u'flow		
Tu =	5.82E-02 days at	1.5 % u'flow		
Tu =	6.61E-02 days at	2.0 % u'flow		

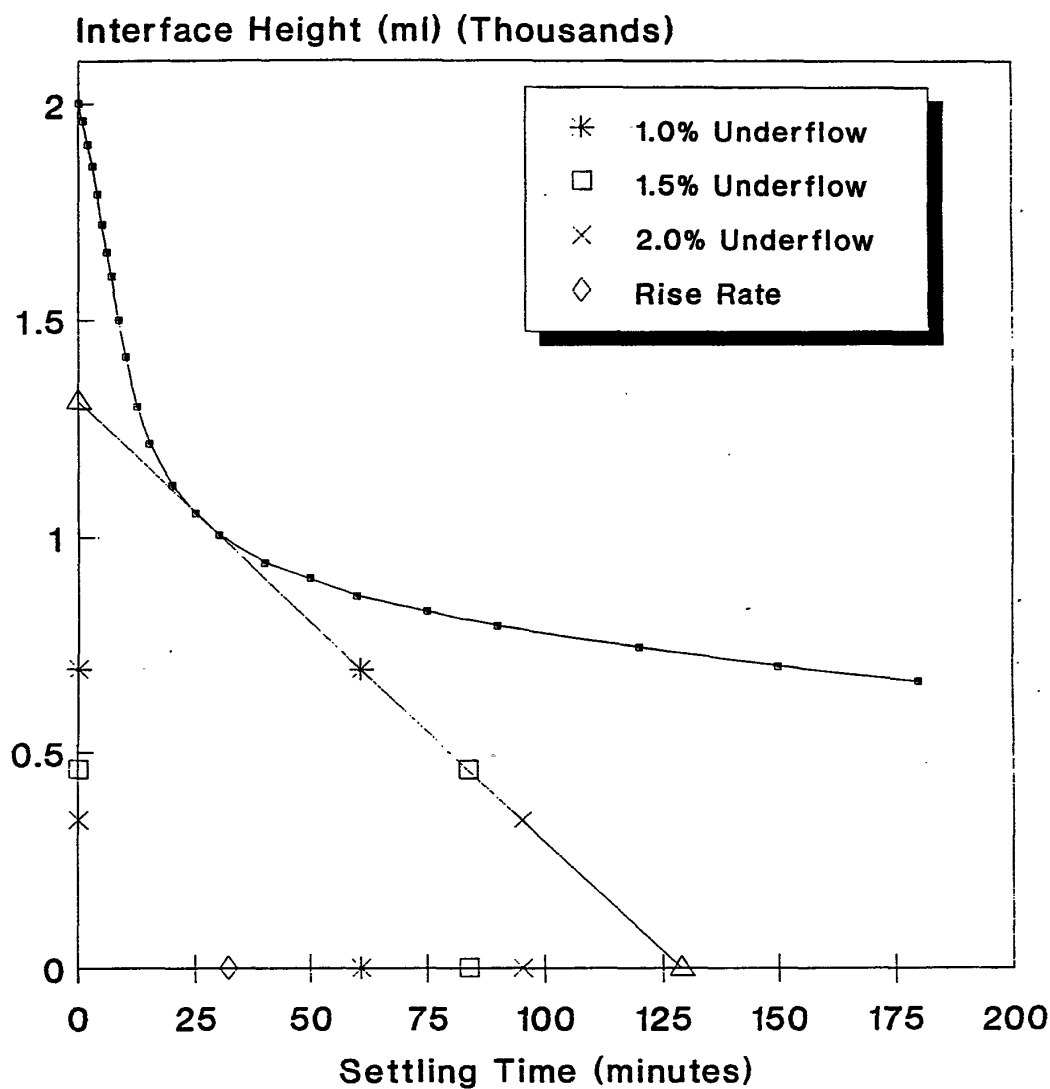
Unit Area at	1.0 % u'flow=	372.48 ft <sup>2</sup> /STPD	(	38.145 m <sup>2</sup> /MTPD)
Unit Area at	1.5 % u'flow=	512.66 ft <sup>2</sup> /STPD	(	52.500 m <sup>2</sup> /MTPD)
Unit Area at	2.0 % u'flow=	582.75 ft <sup>2</sup> /STPD	(	59.678 m <sup>2</sup> /MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 0.15 gpm/ft<sup>2</sup> ( 0.369 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 9: INTERFACE HT. vs. SETTLING TIME  
Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.35%; pH: 6.0 Units  
Floc. Dosage: 5.0 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008605

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: X  
Test No.: 10  
Test Date: May 10, 1  
By: ST  
Location: HRI

Material: 0.02 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 23)  
99.98 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

pH: 6.1 Units  
Temperature: 18 °C  
Floc. Dosage: 0.5 mg/l  
Ferric Source: Ferric Sulfate

**SETTLING DATA**

Time (min)	Interface Height (mls)	Average Percent Solids
0	2000	0.02
0.5	1800	0.02
1	1250	0.03
1.5	700	0.06
2	140	0.28
2.5	120	0.33
3	110	0.36
4	100	0.40
5	90	0.44
6.5	75	0.53
8	60	0.66
10	55	0.72

Flocculant: Percol 351  
Type: Nonionic  
Concentration: 0.05 g/l  
Mls Added: 20 mls  
Picket Speed: 6 rph

Description: Slightly Cloudy Supernatant;  
Heavy Floc. Structure.

**Underflow Measurements:**

Undecanted Volume: 2000 mls  
Slurry & Tare: 3090.4 gms  
Cylinder Weight: 1090.0 gms  
Slurry Weight: 2000.4 gms  
Dry Solids Weight: 0.4 gms  
Supernatant S.G. 3.2  
Solids S.G. 1.0

Settling Vessel Size: 1540 mls/ft  
5052 mls/m  
Ho= 1.30 ft 0.396 m)  
Co= 6.24E-06 ST/ft<sup>3</sup> 2.00E-04 MT/m<sup>3</sup>)

Tu = 2.38E-03 days at 2.0 % u'flow  
Tu = 2.41E-03 days at 2.5 % u'flow  
Tu = 2.43E-03 days at 3.0 % u'flow

Unit Area at 2.0 % u'flow= 366.90 ft<sup>2</sup>/STPD ( 37.574 m<sup>2</sup>/MTPD)  
Unit Area at 2.5 % u'flow= 371.78 ft<sup>2</sup>/STPD ( 38.073 m<sup>2</sup>/MTPD)  
Unit Area at 3.0 % u'flow= 375.03 ft<sup>2</sup>/STPD ( 38.406 m<sup>2</sup>/MTPD)

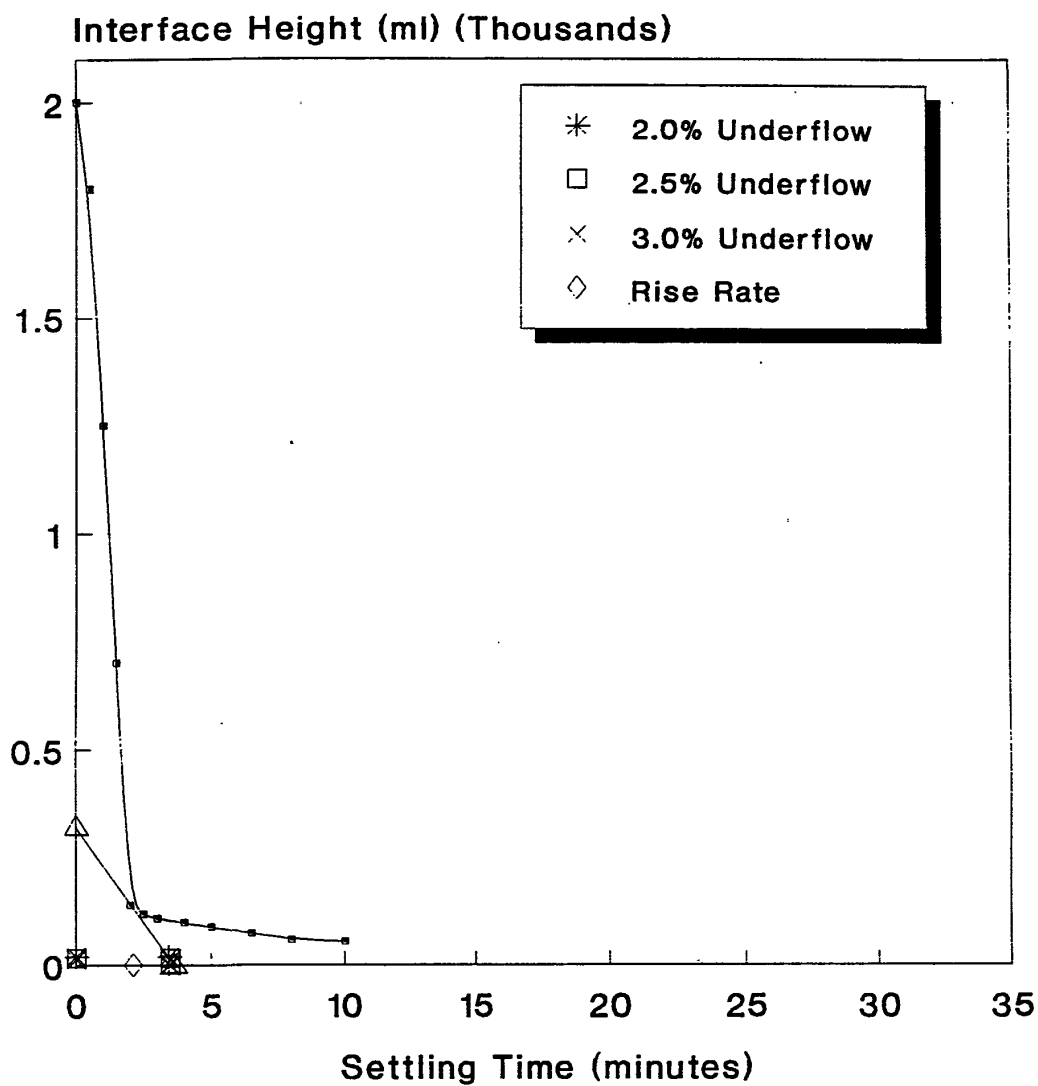
Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 2.29 gpm/ft<sup>2</sup> ( 5.601 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 10: INTERFACE HT. vs. SETTLING TIME

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.02%; pH: 6.1 Units  
Floc. Dosage: 0.5 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008607

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XI  
Test No.: 11  
Test Date: May 10, 1967  
By: ST  
Location: HRI

Material: 0.02 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 23)  
99.98 % Liquid Consisting of Treated Water

**Object of Test:** To Determine Settling Characteristics at Conditions Noted.

pH: 6.1 Units  
Temperature: 18 °C  
Floc. Dosage: 0.75 mg/l  
Ferric Source: Ferric Sulfate

**SETTLING DATA**

**Flocculant:** Percol 351  
**Type:** Nonionic  
**Concentration:** 0.05 g/l  
**Ms Added:** 30 mls  
**Picket Speed:** 6 rph

Time (min)	Interface Height (mls)	Average Percent Solids
0	2000	0.02
0.5	1700	0.02
1	1150	0.03
1.5	300	0.13
2	120	0.33
3	100	0.40
4	80	0.50
5	70	0.57
6.5	60	0.66
8	55	0.72
10	50	0.79

**Description:** Slightly Cloudy Supernatant;  
Heavy Floc. Structure.

**Underflow Measurements:**

Undecanted Volume: 2000 mls  
Slurry & Tare: 3090.4 gms  
Cylinder Weight: 1090.0 gms  
Slurry Weight: 2000.4 gms  
Dry Solids Weight: 0.4 gms  
Supernatant S.G. 3.2  
Solids S.G. 1.0

**Settling Vessel Size:** 1540 mls/ft  
5052 mls/m  
Ho= 1.30 ft 0.396 m)  
Co= 6.24E-06 ST/ft³ 2.00E-04 MT/m³)

Tu = 2.36E-03 days at 2.0 % u'flow  
Tu = 2.40E-03 days at 2.5 % u'flow  
Tu = 2.42E-03 days at 3.0 % u'flow

Unit Area at 2.0 % u'flow= 364.39 ft²/STPD ( 37.317 m²/MTPD)  
Unit Area at 2.5 % u'flow= 369.78 ft²/STPD ( 37.869 m²/MTPD)  
Unit Area at 3.0 % u'flow= 373.37 ft²/STPD ( 38.236 m²/MTPD)

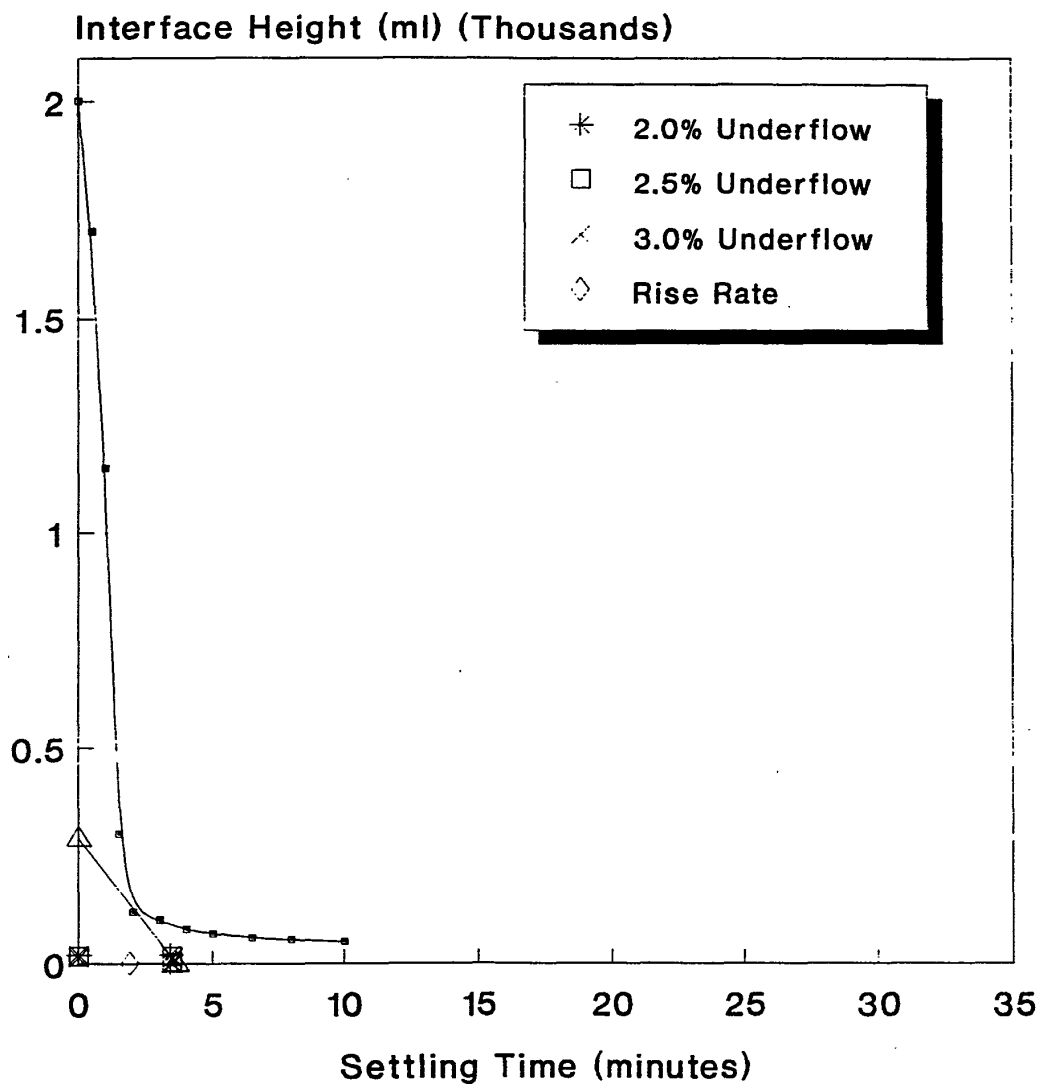
Note: Unit Area Includes a 1.25 Scale-Up Factor.

**Rise Rate =** 2.57 gpm/ft² ( 6.282 m³/(hr\*m²))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 11: INTERFACE HT. vs. SETTLING TIME

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.02%; pH: 6.1 Units  
Floc. Dosage: 0.75 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008609

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XII  
Test No.: 12  
Test Date: May 10, 1988  
By: ST  
Location: HRI

Material: 0.23 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 23)  
99.77 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

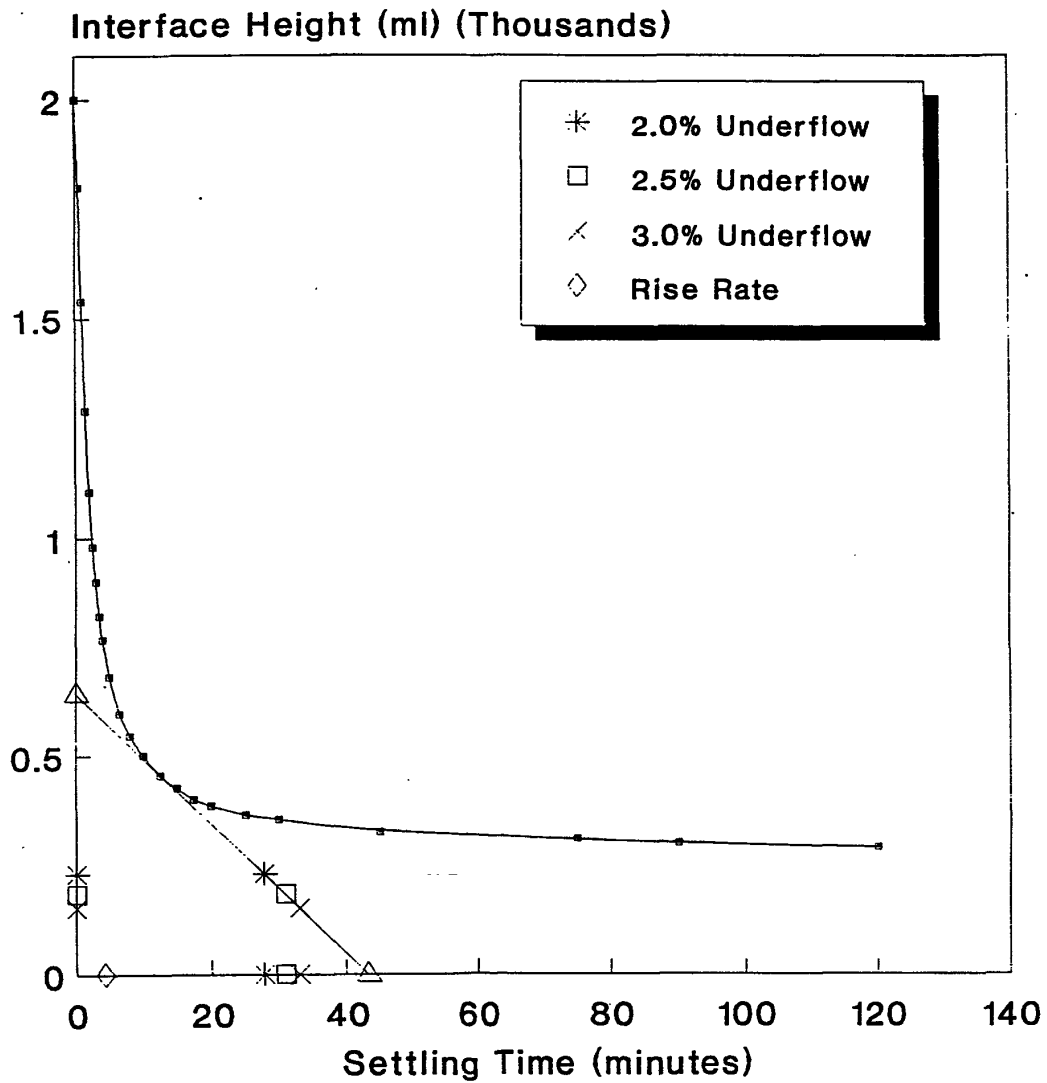
		SETTLING DATA		
		Time	Interface	Average
		(min)	Height	Percent
			(mls)	Solids
pH:	6.1 Units			
Temperature:	18 °C			
Floc. Dosage:	1.25 mg/l			
Ferric Source:	Ferric Sulfate			
<b>Flocculant:</b>	Percol 351	0	2000	0.23
Type:	Nonionic	0.5	1800	0.26
Concentration:	0.05 g/l	1	1540	0.30
Mls Added:	50 mls	1.5	1290	0.36
Picket Speed:	6 rph	2	1105	0.42
		2.5	980	0.48
<b>Description:</b>	Clear Supernatant;	3	900	0.52
	Heavy Floc. Structure.	3.5	820	0.57
		4	765	0.61
<b>Underflow Measurements:</b>		5	680	0.69
Undecanted Volume:	2000 mls	6.5	595	0.78
Slurry & Tare:	3094.7 gms	8	545	0.86
Cylinder Weight:	1090.0 gms	10	500	0.93
Slurry Weight:	2004.7 gms	12.5	455	1.02
Dry Solids Weight:	4.7 gms	15	425	1.09
Supernatant S.G.	3.2	17.5	400	1.16
Solids S.G.	1.0	20	385	1.21
		25	365	1.27
<b>Settling Vessel Size:</b>	1540 mls/ft	30	355	1.31
	5052 mls/m	45	325	1.43
Ho=	1.30 ft	75	310	1.49
Co=	7.34E-05 ST/ft <sup>3</sup>	90	300	1.54
		120	290	1.59
Tu =	1.93E-02 days at	2.0	% u'flow	
Tu =	2.15E-02 days at	2.5	% u'flow	
Tu =	2.29E-02 days at	3.0	% u'flow	
Unit Area at	2.0 % u'flow=	252.92	ft <sup>2</sup> /STPD	( 25.901 m <sup>2</sup> /MTPD)
Unit Area at	2.5 % u'flow=	281.74	ft <sup>2</sup> /STPD	( 28.852 m <sup>2</sup> /MTPD)
Unit Area at	3.0 % u'flow=	300.94	ft <sup>2</sup> /STPD	( 30.819 m <sup>2</sup> /MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 1.14 gpm/ft<sup>2</sup> ( 2.794 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 12: INTERFACE HT. vs. SETTLING TIME**  
Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.23%; pH: 6.1 Units  
Floc. Dosage: 1.25 mg/l



**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008611

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XIII  
Test No.: 13  
Test Date: May 11, 19  
By: ST  
Location: HRI

Material: 0.04 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 25)  
99.96 % Liquid Consisting of Treated Water

**Object of Test:** To Determine Settling Characteristics at Conditions Noted.

pH: 6.2 Units  
Temperature: 20 °C  
Floc. Dosage: 0.5 mg/l  
Ferric Source: Ferric Sulfate

**SETTLING DATA**

**Flocculant:** Percol 351  
**Type:** Nonionic  
**Concentration:** 0.05 g/l  
**Mls Added:** 20 mls  
**Picket Speed:** 6 rph

Time (min)	Interface Height (mls)	Average Percent Solids
0	2000	0.04
0.5	1750	0.05
1	1200	0.07
1.5	300	0.27
2	250	0.32
2.5	225	0.35
3	205	0.39
4	180	0.44
5	160	0.50
6.5	150	0.53
8	140	0.57
10	120	0.66
15	100	0.79

**Description:** Slightly Cloudy Supernatant;  
Heavy Floc. Structure.

**Underflow Measurements:**

Undecanted Volume: 2000 mls  
Slurry & Tare: 3090.8 gms  
Cylinder Weight: 1090.0 gms  
Slurry Weight: 2000.8 gms  
Dry Solids Weight: 0.8 gms  
Supernatant S.G. 3.2  
Solids S.G. 1.0

**Settling Vessel Size:** 1540 mls/ft  
5052 mls/m  
Ho= 1.30 ft 0.396 m)  
Co= 1.25E-05 ST/ft³ 4.00E-04 MT/m³)

Tu = 2.63E-03 days at 2.0 % u'flow  
Tu = 2.67E-03 days at 2.5 % u'flow  
Tu = 2.71E-03 days at 3.0 % u'flow

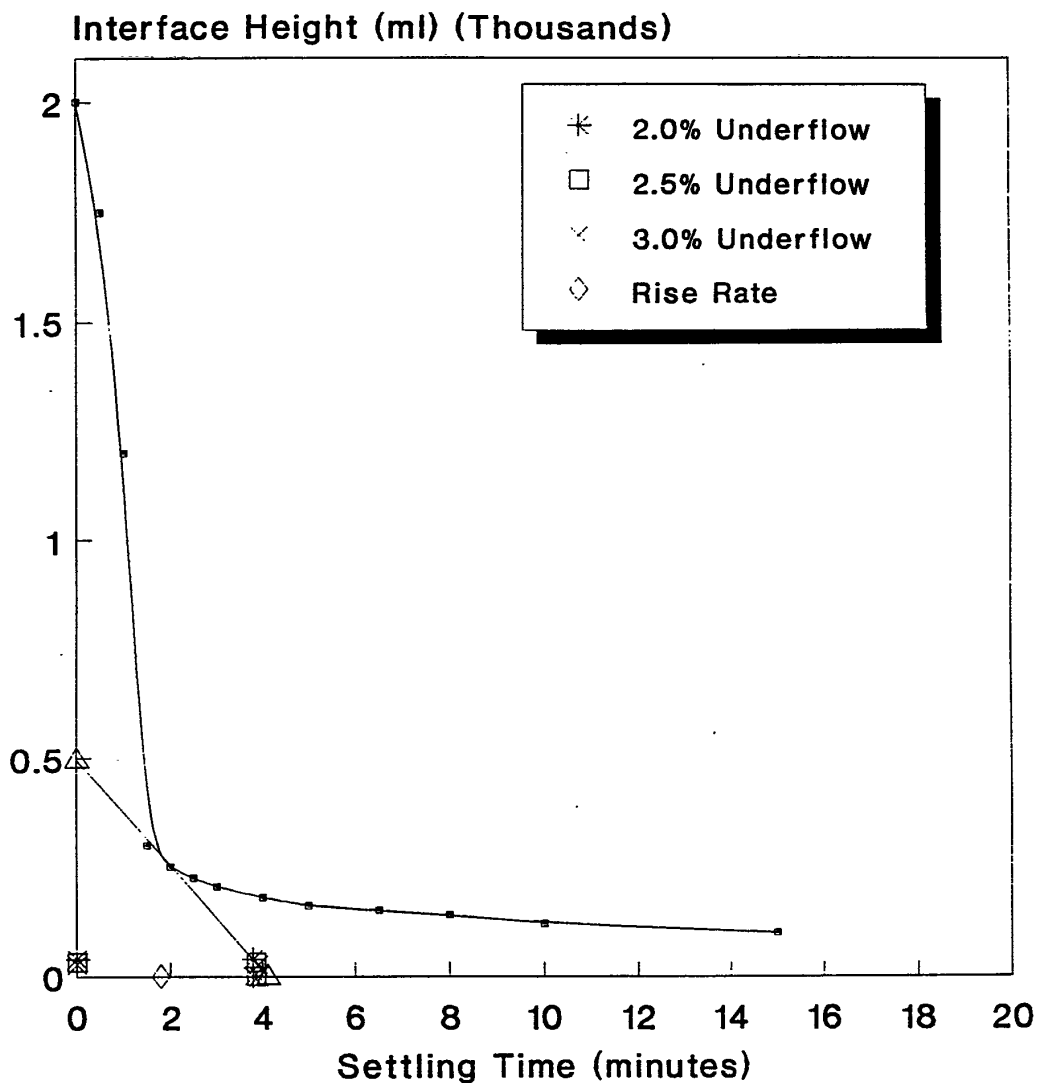
**Unit Area at** 2.0 % u'flow= 202.64 ft²/STPD ( 20.752 m²/MTPD)  
**Unit Area at** 2.5 % u'flow= 206.19 ft²/STPD ( 21.115 m²/MTPD)  
**Unit Area at** 3.0 % u'flow= 208.55 ft²/STPD ( 21.358 m²/MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

**Rise Rate =** 2.71 gpm/ft² ( 6.633 m³/(hr\*m²))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 13: INTERFACE HT. vs. SETTLING TIME**  
**Hazen Research, Inc.**  
**Arsenic Removal Project**



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.04%; pH: 6.2 Units  
Floc. Dosage: 0.5 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008613

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XIV  
Test No.: 14  
Test Date: May 11,  
By: ST  
Location: HRI

Material: 0.04 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 25)  
99.96 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

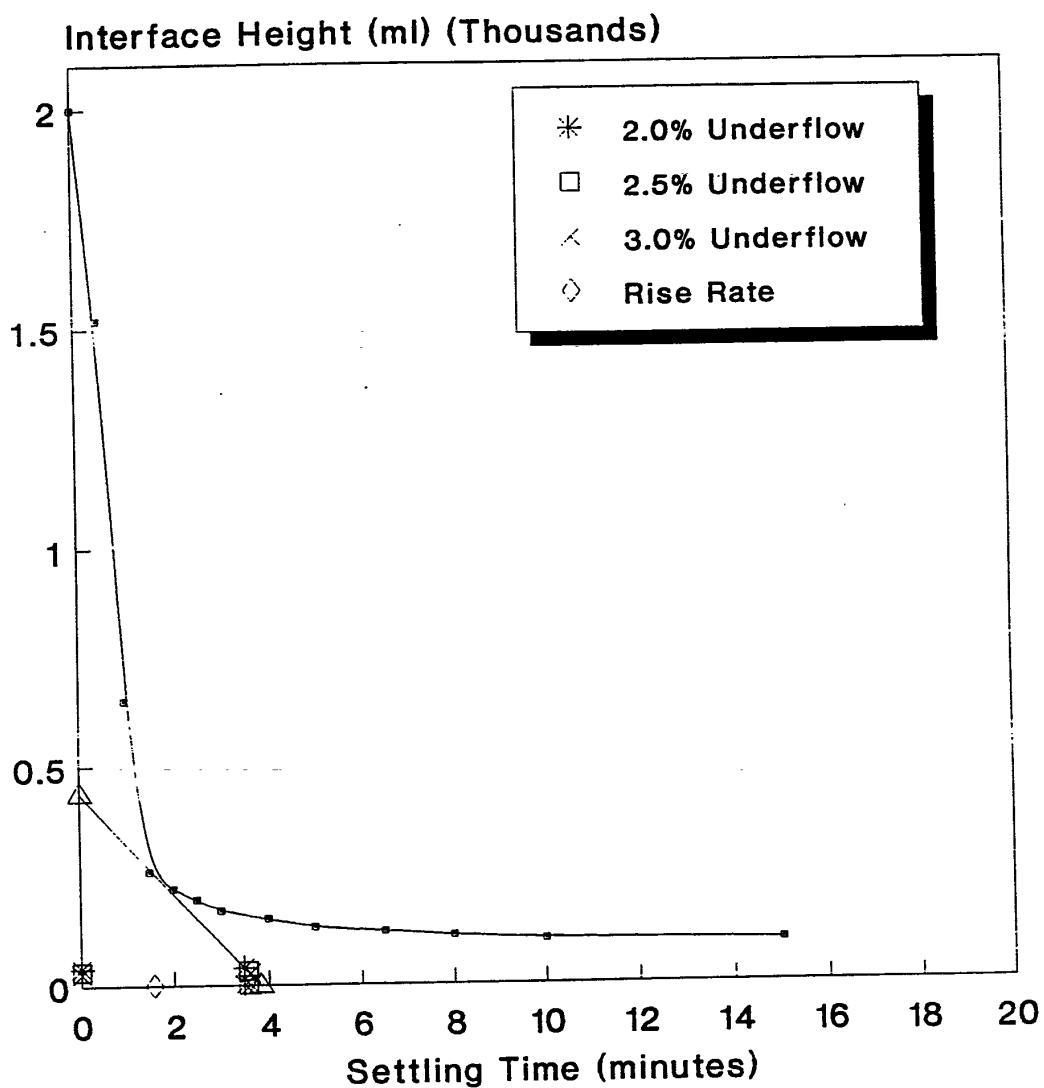
		SETTLING DATA		
		Time	Interface	Average
		(min)	Height	Percent
			(mls)	Solids
pH:	6.2 Units			
Temperature:	20 °C			
Floc. Dosage:	0.75 mg/l			
Ferric Source:	Ferric Sulfate			
<b>Flocculant:</b>	Percol 351	0	2000	0.04
Type:	Nonionic	0.5	1520	0.05
Concentration:	0.05 g/l	1	650	0.12
Ms Added:	30 mls	1.5	260	0.31
Picket Speed:	6 rph	2	220	0.36
		2.5	195	0.41
<b>Description:</b>	Slightly Cloudy Supernatant;	3	170	0.47
	Very Heavy Floc. Structure.	4	150	0.53
		5	130	0.61
<b>Underflow Measurements:</b>		6.5	120	0.66
Undecanted Volume:	2000 mls	8	110	0.72
Slurry & Tare:	3090.8 gms	10	100	0.79
Cylinder Weight:	1090.0 gms	15	95	0.84
Slurry Weight:	2000.8 gms			
Dry Solids Weight:	0.8 gms			
Supernatant S.G.	3.2			
Solids S.G.	1.0			
<b>Settling Vessel Size:</b>	1540 mls/ft			
	5052 mls/m			
Ho=	1.30 ft			
	0.396 m)			
Co=	1.25E-05 ST/ft <sup>3</sup>			
	4.00E-04 MT/m <sup>3</sup> )			
Tu =	2.42E-03 days at	2.0	% u'flow	
Tu =	2.46E-03 days at	2.5	% u'flow	
Tu =	2.50E-03 days at	3.0	% u'flow	
Unit Area at	2.0 % u'flow=	186.27 ft <sup>2</sup> /STPD	(	19.076 m <sup>2</sup> /MTPD)
Unit Area at	2.5 % u'flow=	189.99 ft <sup>2</sup> /STPD	(	19.457 m <sup>2</sup> /MTPD)
Unit Area at	3.0 % u'flow=	192.47 ft <sup>2</sup> /STPD	(	19.711 m <sup>2</sup> /MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 3.09 gpm/ft<sup>2</sup> ( 7.563 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

**FIG. 14: INTERFACE HT. vs. SETTLING TIME**  
**Hazen Research, Inc.**  
**Arsenic Removal Project**



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.04%; pH: 6.2 Units  
Floc. Dosage: 0.75 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008615

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XV  
Test No.: 15  
Test Date: May 11, 199  
By: ST  
Location: HRI

Material: 0.43 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 25)  
99.57 % Liquid Consisting of Treated Water

**Object of Test:** To Determine Settling Characteristics at Conditions Noted.

pH:	6.2 Units	<b>SETTLING DATA</b>		
Temperature:	20 °C	Time	Interface	Average
Floc. Dosage:	1.25 mg/l	(min)	Height	Percent
Ferric Source:	Ferric Sulfate		(mls)	Solids
<b>Flocculant:</b>	Percol 351	0	2000	0.43
Type:	Nonionic	0.5	1980	0.43
Concentration:	0.05 g/l	1	1960	0.44
Mls Added:	50 mls	1.5	1940	0.44
Picket Speed:	6 rph	2	1910	0.45
		2.5	1875	0.46
<b>Description:</b>	Clear Cloudy Supernatant;	3	1825	0.47
	Medium to Heavy Floc. Structure.	4	1745	0.49
		5	1655	0.52
<b>Underflow Measurements:</b>		6	1555	0.55
Undecanted Volume:	2000 mls	7	1450	0.59
Slurry & Tare:	3098.6 gms	8	1340	0.64
Cylinder Weight:	1090.0 gms	9	1245	0.69
Slurry Weight:	2008.6 gms	10	1180	0.72
Dry Solids Weight:	8.6 gms	12.5	1025	0.83
Supernatant S.G.	3.2	15	915	0.93
Solids S.G.	1.0	17.5	850	1.00
		20	795	1.07
<b>Settling Vessel Size:</b>	1540 mls/ft	25	710	1.20
	5052 mls/m	30	660	1.29
Ho=	1.30 ft	40	605	1.40
Co=	1.34E-04 ST/ft³	50	580	1.46
		60	550	1.54
Tu =	3.25E-02 days at	75	525	1.61
	2.0 % u'flow	90	505	1.67
Tu =	3.69E-02 days at	120	485	1.74
	2.5 % u'flow			
Tu =	3.98E-02 days at			
	3.0 % u'flow			
<b>Unit Area at</b>	2.0 % u'flow=	233.13 ft²/STPD	(	23.874 m²/MTPD)
<b>Unit Area at</b>	2.5 % u'flow=	264.54 ft²/STPD	(	27.091 m²/MTPD)
<b>Unit Area at</b>	3.0 % u'flow=	285.48 ft²/STPD	(	29.235 m²/MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

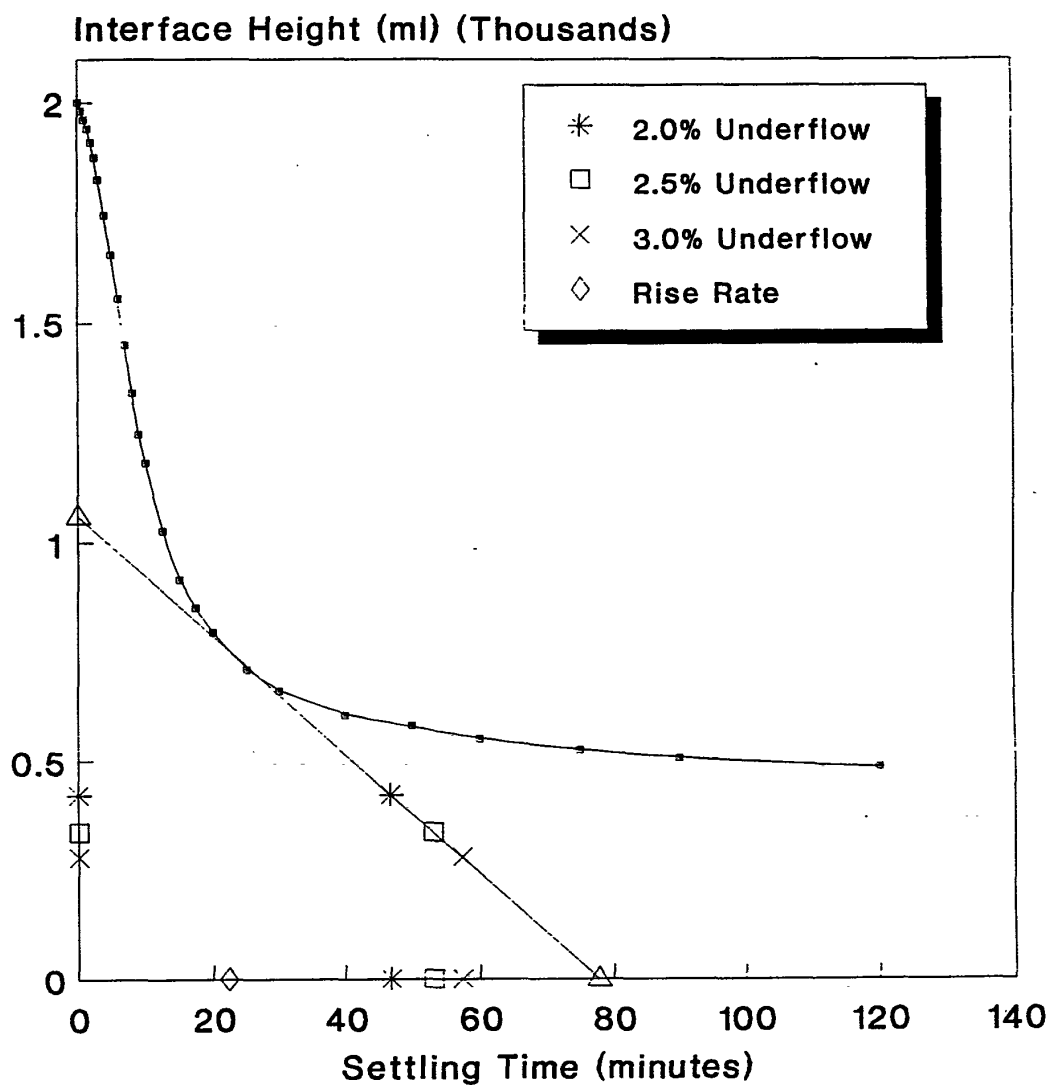
**Rise Rate =** 0.22 gpm/ft² ( 0.533 m³/(hr\*m²))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 15: INTERFACE HT. vs. SETTLING TIME

Hazen Research, Inc.

Arsenic Removal Project



Material: Ferric Hydroxide Precipitate

Feed Solids: 0.43%; pH: 6.2 Units

Floc. Dosage: 1.25 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008617

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XVI  
Test No.: 16  
Test Date: May 12,  
By: ST  
Location: HRI

Material: 0.08 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 27)  
99.92 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

pH: 6.2 Units  
Temperature: 18 °C  
Floc. Dosage: 0.375 mg/l  
Ferric Source: Ferric Sulfate

**SETTLING DATA**

Flocculant: Percol 351  
Type: Nonionic  
Concentration: 0.05 g/l  
Mls Added: 15 mls  
Picket Speed: 6 rph

Time (min)	Interface Height (mls)	Average Percent Solids
0	2000	0.08
0.5	1800	0.09
1	1420	0.11
1.5	950	0.17
2	460	0.35
2.5	395	0.40
3	355	0.45
4	305	0.52
5	275	0.58
6.5	230	0.69
8	205	0.77
10	175	0.91
12.5	160	0.99
15	150	1.06
20	135	1.17

Description: Slightly Cloudy Supernatant;  
Heavy Floc. Structure.

**Underflow Measurements:**

Undecanted Volume: 2000 mls  
Slurry & Tare: 3091.6 gms  
Cylinder Weight: 1090.0 gms  
Slurry Weight: 2001.6 gms  
Dry Solids Weight: 1.6 gms  
Supernatant S.G. 3.2  
Solids S.G. 1.0

Settling Vessel Size: 1540 mls/ft  
5052 mls/m  
Ho= 1.30 ft 0.396 m)  
Co= 2.50E-05 ST/ft<sup>3</sup> 8.00E-04 MT/m<sup>3</sup>)

Tu = 4.06E-03 days at 2.0 % u'flow  
Tu = 4.18E-03 days at 2.5 % u'flow  
Tu = 4.26E-03 days at 3.0 % u'flow

Unit Area at 2.0 % u'flow= 156.57 ft<sup>2</sup>/STPD ( 16.035 m<sup>2</sup>/MTPD)  
Unit Area at 2.5 % u'flow= 161.06 ft<sup>2</sup>/STPD ( 16.493 m<sup>2</sup>/MTPD)  
Unit Area at 3.0 % u'flow= 164.04 ft<sup>2</sup>/STPD ( 16.799 m<sup>2</sup>/MTPD)

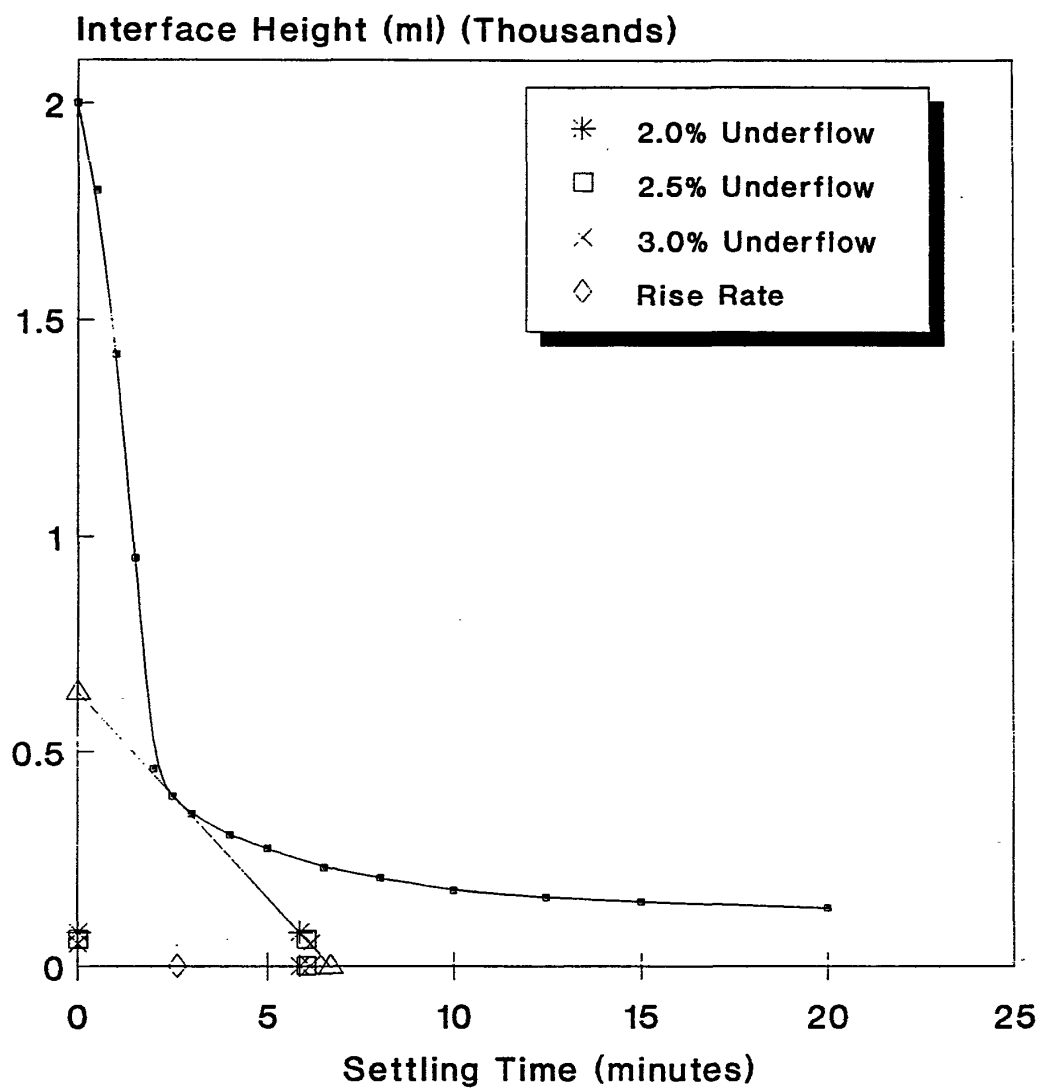
Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 1.86 gpm/ft<sup>2</sup> ( 4.549 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 16: INTERFACE HT. vs. SETTLING TIME

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.08%; pH: 6.2 Units  
Floc. Dosage: 0.375 mg/l



**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008619

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XVII  
Test No.: 17  
Test Date: May 12, 1  
By: ST  
Location: HRI

Material: 0.08 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 27)  
99.92 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

		SETTLING DATA		
		Time (min)	Interface Height (mls)	Average Percent Solids
pH:	6.2 Units			
Temperature:	18 °C			
Floc. Dosage:	0.5 mg/l			
Ferric Source:	Ferric Sulfate			
<b>Flocculant:</b>	Percol 351	0	2000	0.08
Type:	Nonionic	0.5	1660	0.10
Concentration:	0.05 g/l	1	1040	0.15
Mls Added:	20 mls	1.5	425	0.38
Picket Speed:	6 rph	2	360	0.44
		2.5	320	0.50
<b>Description:</b>	Slightly Cloudy Supernatant;	3	295	0.54
	Very Heavy Floc. Structure.	4	255	0.62
		5	230	0.69
<b>Underflow Measurements:</b>		6.5	200	0.79
Undecanted Volume:	2000 mls	8	175	0.91
Slurry & Tare:	3091.6 gms	10	160	0.99
Cylinder Weight:	1090.0 gms	12.5	145	1.09
Slurry Weight:	2001.6 gms	15	140	1.13
Dry Solids Weight:	1.6 gms			
Supernatant S.G.	3.2			
Solids S.G.	1.0			
<b>Settling Vessel Size:</b>	1540 mls/ft			
	5052 mls/m			
Ho=	1.30 ft			
Co=	2.50E-05 ST/ft <sup>3</sup>			
				0.396 m)
				8.00E-04 MT/m <sup>3</sup> )
Tu =	3.10E-03 days at			2.0 % u'flow
Tu =	3.20E-03 days at			2.5 % u'flow
Tu =	3.26E-03 days at			3.0 % u'flow
<b>Unit Area at</b>	2.0 % u'flow=	119.47 ft <sup>2</sup> /STPD	(	12.234 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	2.5 % u'flow=	123.16 ft <sup>2</sup> /STPD	(	12.613 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	3.0 % u'flow=	125.63 ft <sup>2</sup> /STPD	(	12.865 m <sup>2</sup> /MTPD)

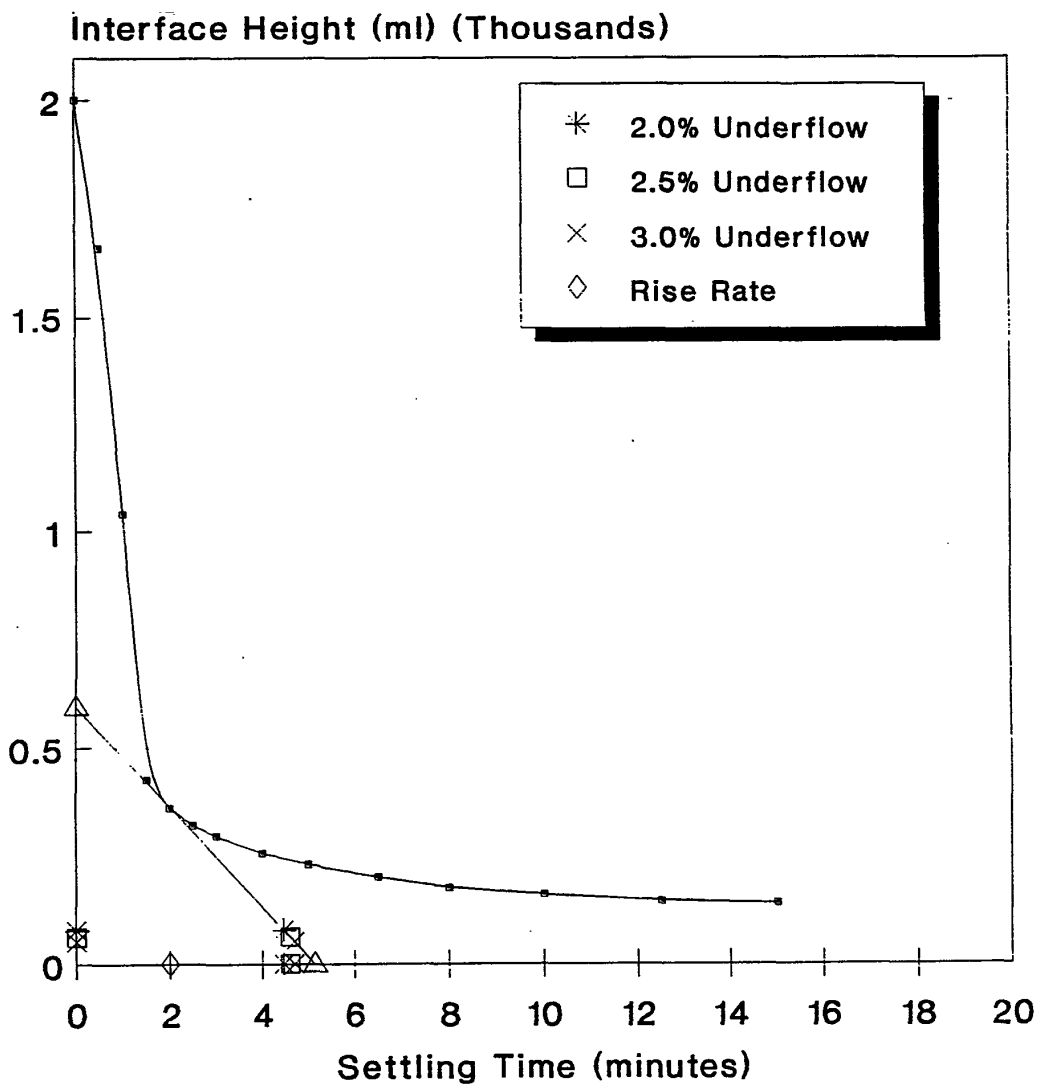
Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 2.43 gpm/ft<sup>2</sup> ( 5.937 m<sup>3</sup>/(hr\*m<sup>2</sup>))

Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 17: INTERFACE HT. vs. SETTLING TIME

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.08%; pH: 6.2 Units  
Floc. Dosage: 0.5 mg/l

**POCOCK INDUSTRIAL, INC.  
THICKENER TEST DATA SHEET**

008621

Company: Hazen Research, Inc.  
Project: Arsenic Removal Project

Table No.: XVIII  
Test No.: 18  
Test Date: May 12,  
By: ST  
Location: HRI

Material: 0.56 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 27)  
99.44 % Liquid Consisting of Treated Water

Object of Test: To Determine Settling Characteristics at Conditions Noted.

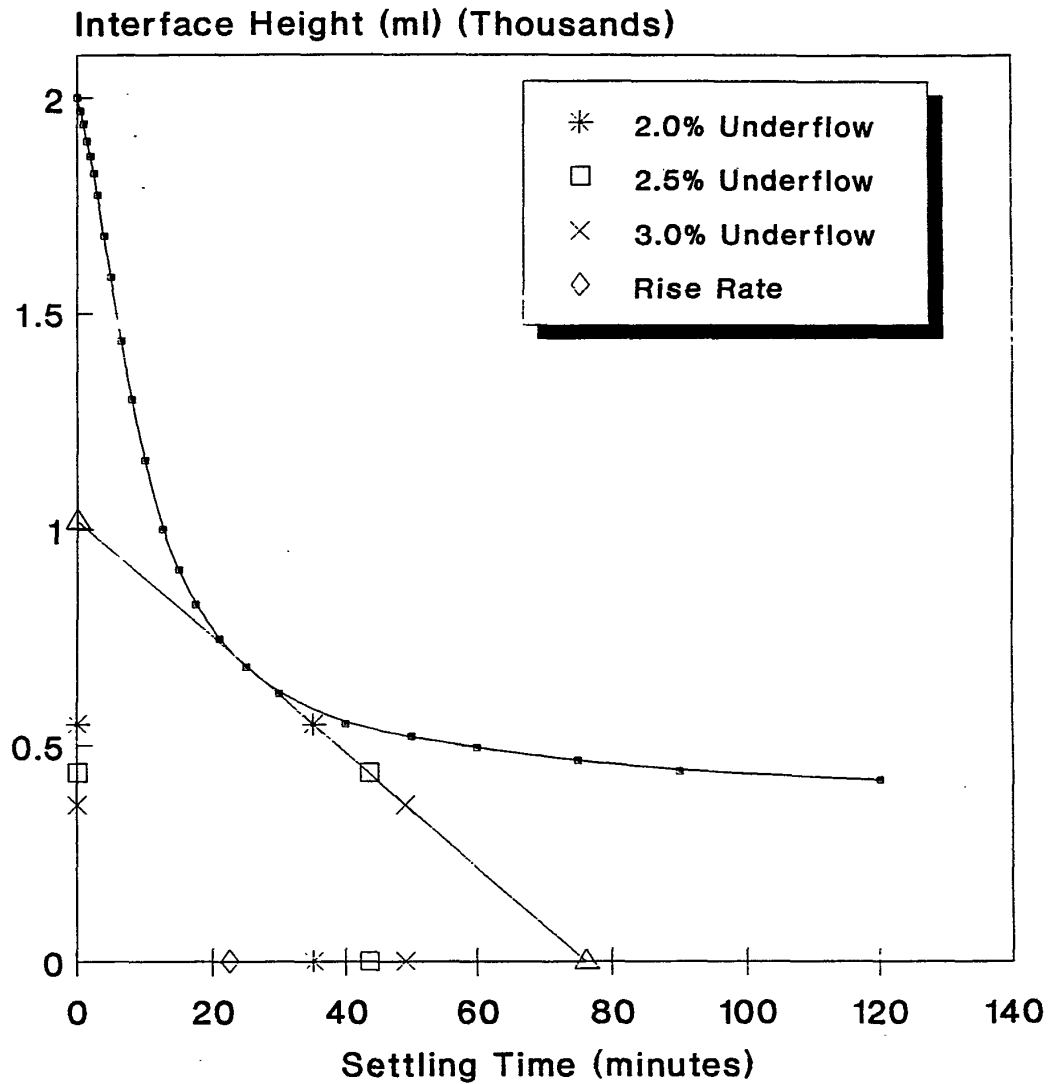
		SETTLING DATA		
		Time (min)	Interface Height (mls)	Average Percent Solids
pH:	6.2 Units			
Temperature:	18 °C			
Floc. Dosage:	0.75 mg/l			
Ferric Source:	Ferric Sulfate			
<b>Flocculant:</b>	Percol 351	0	2000	0.56
Type:	Nonionic	0.5	1970	0.57
Concentration:	0.05 g/l	1	1940	0.57
Mls Added:	30 mls	1.5	1900	0.59
Picket Speed:	6 rph	2	1865	0.60
		2.5	1825	0.61
<b>Description:</b>	Clear Supernatant;	3	1775	0.63
	Medium to Heavy Floc. Structure.	4	1680	0.66
		5	1585	0.70
<b>Underflow Measurements:</b>		6.5	1435	0.77
Undecanted Volume:	2000 mls	8	1300	0.85
Slurry & Tare:	3101.2 gms	10	1160	0.96
Cylinder Weight:	1090.0 gms	12.5	1000	1.11
Slurry Weight:	2011.2 gms	15	905	1.22
Dry Solids Weight:	11.2 gms	17.5	825	1.34
Supernatant S.G.	3.2	21	745	1.48
Solids S.G.	1.0	25	680	1.62
		30	620	1.77
<b>Settling Vessel Size:</b>	1540 mls/ft	40	550	2.00
	5052 mls/m	50	520	2.11
Ho=	1.30 ft	60	495	2.21
Co=	1.75E-04 ST/ft <sup>3</sup>	75	465	2.35
		90	440	2.48
Tu =	2.44E-02 days at	120	420	2.60
	2.0 % u'flow			
Tu =	3.02E-02 days at			
	2.5 % u'flow			
Tu =	3.41E-02 days at			
	3.0 % u'flow			
<b>Unit Area at</b>	2.0 % u'flow=	134.43 ft <sup>2</sup> /STPD	(	13.767 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	2.5 % u'flow=	166.46 ft <sup>2</sup> /STPD	(	17.047 m <sup>2</sup> /MTPD)
<b>Unit Area at</b>	3.0 % u'flow=	187.82 ft <sup>2</sup> /STPD	(	19.234 m <sup>2</sup> /MTPD)

Note: Unit Area Includes a 1.25 Scale-Up Factor.

Rise Rate = 0.22 gpm/ft<sup>2</sup> ( 0.527 m<sup>3</sup>/(hr\*m<sup>2</sup>))  
Note: Rise Rate Includes a 0.5 Scale-Up Factor.

FIG. 18: INTERFACE HT. vs. SETTLING TIME

Hazen Research, Inc.  
Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Feed Solids: 0.56%; pH: 6.2 Units  
Floc. Dosage: 0.75 mg/l

008623

**POCOCK INDUSTRIAL, INC**  
**Rheological Properties Data Sheet**

Company: Hazen Research, Inc.  
 Project: Arsenic Removal Project

Table No.: XIX  
 Test No.: 19  
 Test Date: 05/09/94  
 By: ST  
 Location: HRI

1.11 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 22) - Thickener Underflow  
 98.89 % Liquid Consisting of Treated Water

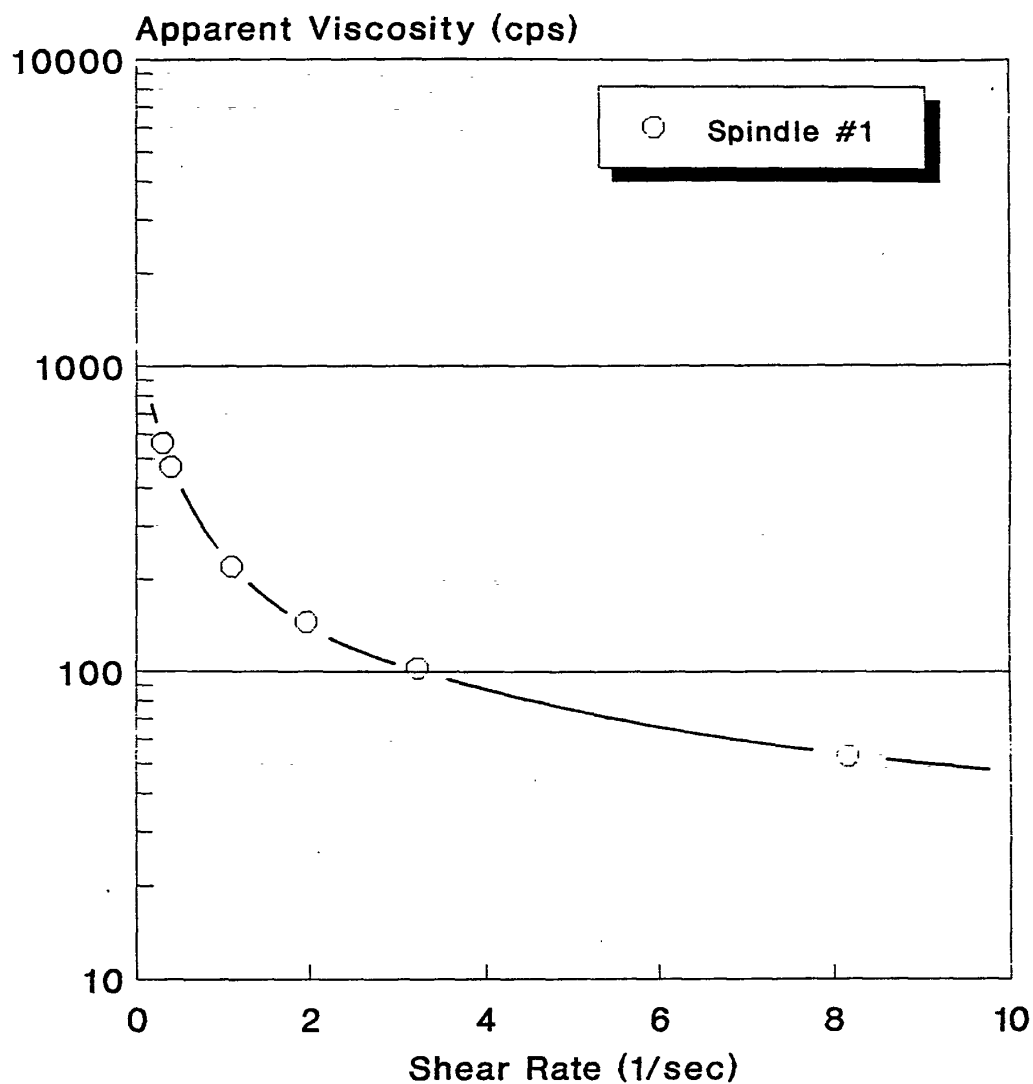
Floc Type: Nonionic Polyacrylamide  
 Floc Dosage: 1.25 mg/l  
 Floc Conc: 0.05 g/l

pH: 6.0 Units  
 Temp: 20 °C

Ferric Source: Ferric Chloride  
 Reference: Thickening Test 4  
 Table IV

Spindle Type:		Cylindrical					
Spindle No.:		1					
Spindle Length:		7.493 cm					
Spindle Radius:		0.9421 cm					
RPM	Reading	Shear Stress	Shear Rate	Apparent Viscosity	Constants and Sums		
0.3	10.2	1.64	0.29	562.55	N =	8.00	
0.6	11.0	1.77	0.38	469.38	H =	-0.35	
1.5	14.9	2.40	1.09	221.01	E =	36.35	
3	17.7	2.85	1.96	145.28	n =	0.29	
6	20.4	3.29	3.22	102.28	F =	10.53	
12	26.7	4.31	8.16	52.76	I =	0.61	
30	38.0	6.12	27.49	22.27	G =	0.51	
60	44.2	7.12	46.40	15.35	k =	2.34	

**FIG. 19: RHEOLOGICAL PROPERTIES**  
**Apparent Viscosity vs. Shear Rate**  
Hazen Research / Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Ferric Source: Ferric Chloride  
Thk U'Flow Solids Concentration: 1.11%

008625

**POCOCK INDUSTRIAL, INC**  
**Rheological Properties Data Sheet**

Company: Hazen Research, Inc.  
 Project: Arsenic Removal Project

Table No.: XX  
 Test No.: 20  
 Test Date: 05/10/94  
 By: ST  
 Location: HRI

0.86 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 24) - Thickener Underflow  
 99.14 % Liquid Consisting of Treated Water

Floc Type: Nonionic Polyacrylamide  
 Floc Dosage: 2.5 mg/l  
 Floc Conc: 0.1 g/l

pH: 5.8 Units  
 Temp: 18 °C

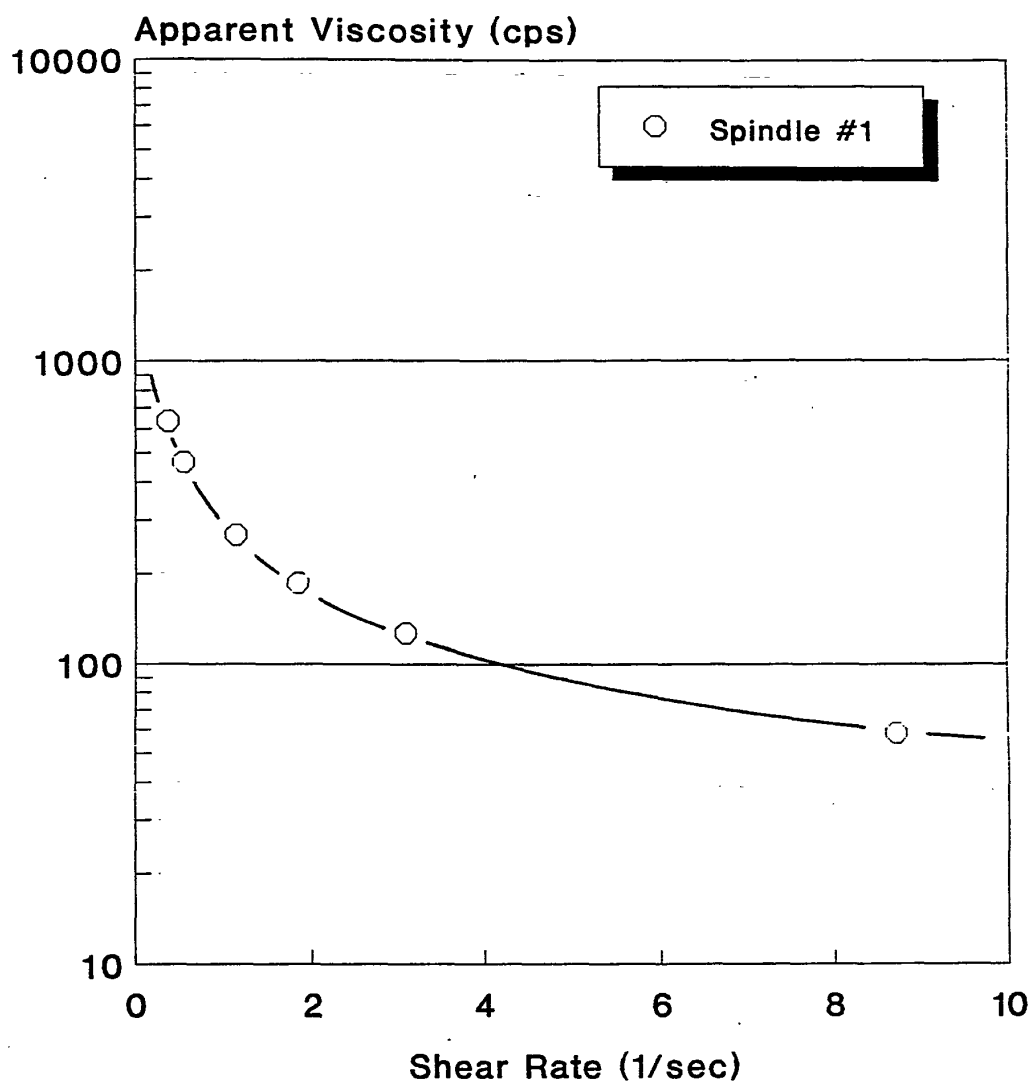
Ferric Source: Ferric Chloride  
 Reference: Thickening Test 6  
 Table VI

Spindle Type:	Cylindrical
Spindle No.:	1
Spindle Length:	7.493 cm
Spindle Radius:	0.9421 cm

RPM	Reading	Shear Stress	Shear Rate	Apparent Viscosity	Constants and Sums	
0.3	14.0	2.25	0.36	634.39	N =	8.00
0.6	15.5	2.50	0.54	465.10	H =	-0.35
1.5	18.8	3.02	1.13	267.66	E =	36.35
3	21.2	3.42	1.84	185.93	n =	0.25
6	24.2	3.90	3.08	126.79	F =	9.24
12	31.5	5.08	8.72	58.28	I =	0.69
30	44.0	7.10	32.44	21.88	G =	0.61
60	52.4	8.45	64.28	13.14	k =	2.93

**FIG. 20: RHEOLOGICAL PROPERTIES**  
**Apparent Viscosity vs. Shear Rate**  
Hazen Research / Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Ferric Source: Ferric Chloride  
Thk U'Flow Solids Concentration: 0.86%



**POCOCK INDUSTRIAL, INC**  
**Rheological Properties Data Sheet**

008627

Company: Hazen Research, Inc.  
 Project: Arsenic Removal Project

Table No.: XXI  
 Test No.: 21  
 Test Date: 05/12/94  
 By: ST  
 Location: HRI

1.04 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 26) - Thickener Underflow  
 98.96 % Liquid Consisting of Treated Water

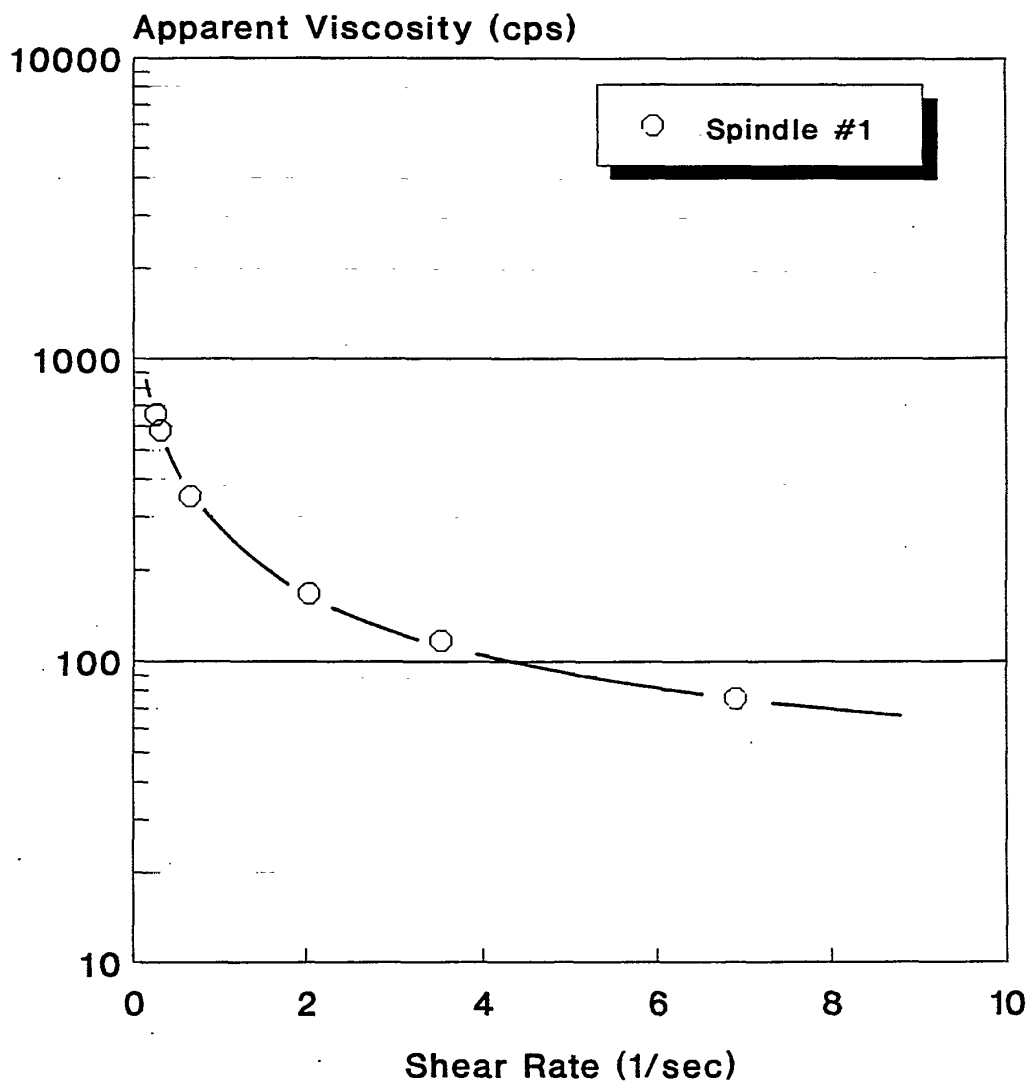
Floc Type: Nonionic Polyscrylamide  
 Floc Dosage: 5.0 mg/l  
 Floc Conc: 0.1 g/l

pH: 6.0 Units  
 Temp: 20 °C

Ferric Source: Ferric Chloride  
 Reference: Thickening Test 9  
 Table IX

Spindle Type:		Cylindrical				
Spindle No.:		1				
Spindle Length:		7.493 cm				
Spindle Radius:		0.9421 cm				
RPM	Reading	Shear Stress	Shear Rate	Apparent Viscosity	Constants and Sums	
0.3	10.2	1.64	0.25	654.78	N =	8.00
0.6	10.9	1.75	0.30	578.25	H =	-0.35
1.5	14.2	2.29	0.65	350.60	E =	36.35
3	21.1	3.40	2.03	167.69	n =	0.35
6	25.6	4.13	3.53	116.84	F =	12.67
12	32.3	5.21	6.91	75.49	I =	0.69
30	45.1	7.26	17.89	40.61	G =	0.57
60	59.9	9.66	40.52	23.84	k =	2.66

**FIG. 21: RHEOLOGICAL PROPERTIES**  
**Apparent Viscosity vs. Shear Rate**  
Hazen Research / Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Ferric Source: Ferric Chloride  
Thk U'Flow Solids Concentration: 1.04%

008629

**POCOCK INDUSTRIAL, INC**  
**Rheological Properties Data Sheet**

Company: Hazen Research, Inc.  
 Project: Arsenic Removal Project

Table No.: XXII  
 Test No.: 22  
 Test Date: 05/11/94  
 By: ST  
 Location: HRI

1.74 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 25) - Thickener Underflow  
 98.26 % Liquid Consisting of Treated Water

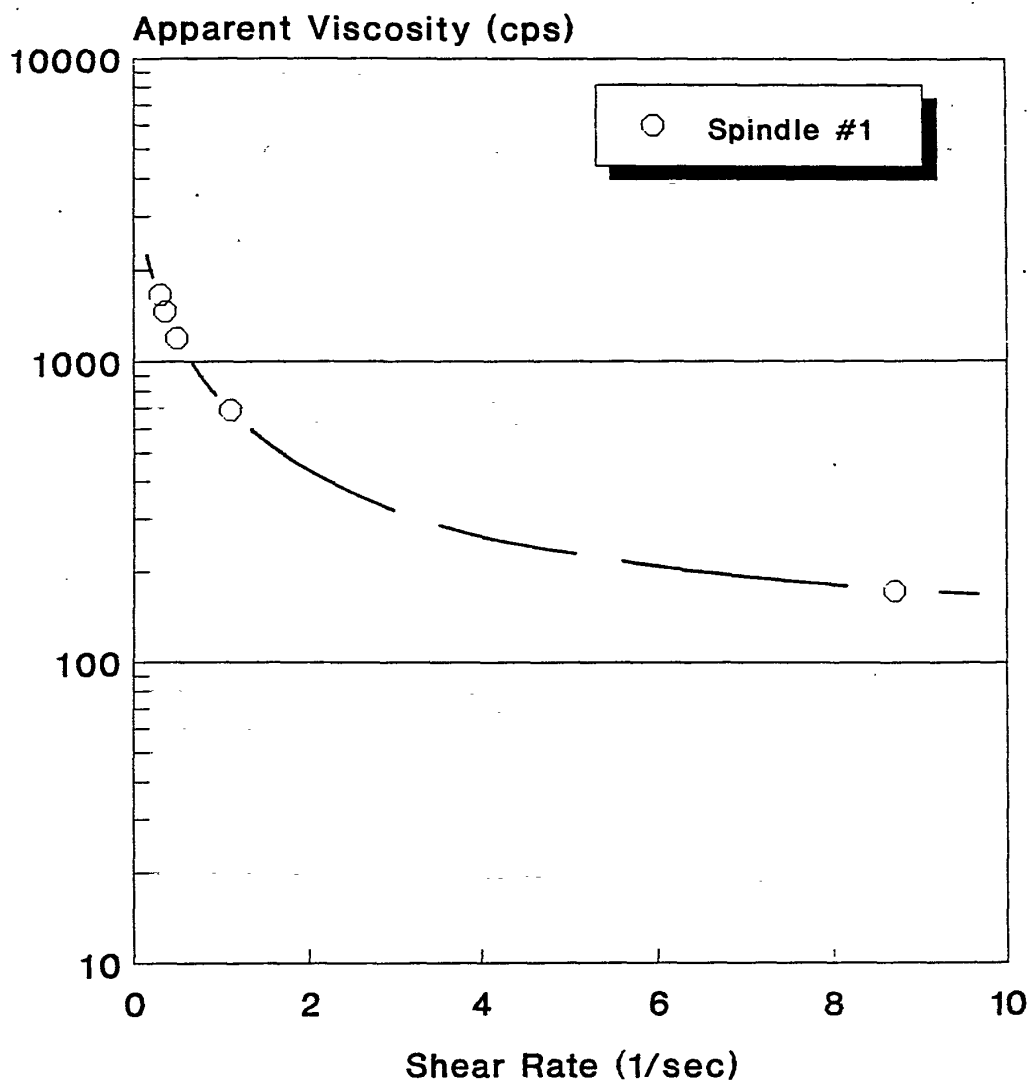
Floc Type: Nonionic Polyacrylamide  
 Floc Dosage: 1.25 mg/l  
 Floc Conc: 0.05 g/l

pH: 6.2 Units  
 Temp: 20 °C

Ferric Source: Ferric Sulfate  
 Reference: Thickening Test 15  
 Table XV

Spindle Type:		Cylindrical				
Spindle No.:		1				
Spindle Length:		7.493 cm				
Spindle Radius:		0.9421 cm				
RPM	Reading	Shear Stress	Shear Rate	Apparent Viscosity	Constants and Sums	
0.3	32.0	5.16	0.35	1458.27	N =	5.00
0.6	30.0	4.84	0.29	1654.28	H =	-0.84
1.5	35.4	5.71	0.48	1189.47	E =	5.46
3	46.6	7.51	1.09	690.03	n =	0.33
6	93.3	15.04	8.72	172.40	F =	1.82
12					I =	1.12
30					G =	0.84
60					k =	7.30

**FIG. 22: RHEOLOGICAL PROPERTIES**  
**Apparent Viscosity vs. Shear Rate**  
Hazen Research / Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Ferric Source: Ferric Sulfate  
Thk U'Flow Solids Concentration: 1.74%

008631

**POCOCK INDUSTRIAL, INC**  
**Rheological Properties Data Sheet**

Company: Hazen Research, Inc.  
 Project: Arsenic Removal Project

Table No.: XXIII  
 Test No.: 23  
 Test Date: 05/12/94  
 By: ST  
 Location: HRI

2.60 % Solids Consisting of Ferric Hydroxide Precipitate (Test No. 27) - Thickener Underflow  
 97.40 % Liquid Consisting of Treated Water

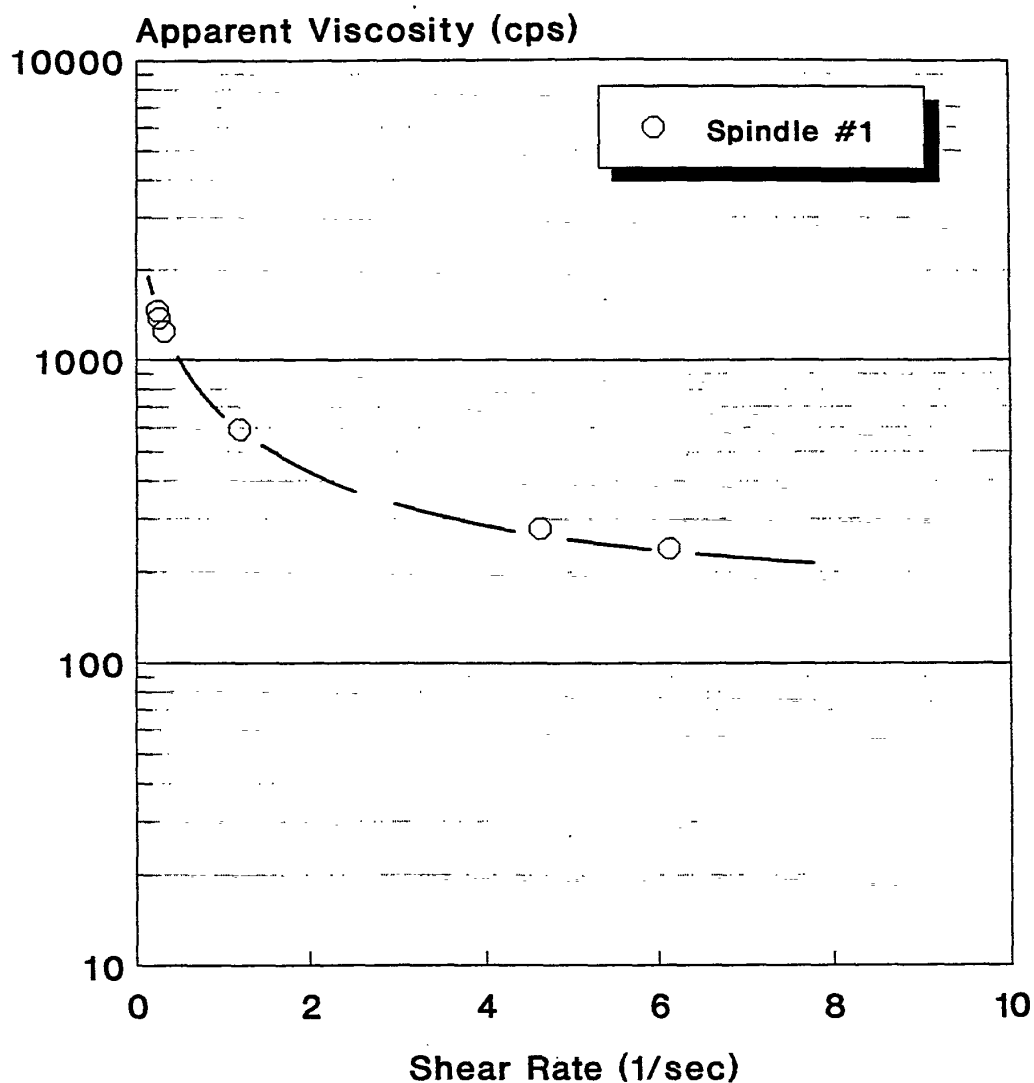
Floc Type: Nonionic Polyacrylamide  
 Floc Dosage: 0.75 mg/l  
 Floc Conc: 0.05 g/l

pH: 6.2 Units  
 Temp: 18 °C

Ferric Source: Ferric Sulfate  
 Reference: Thickening Test 18  
 Table XVIII

Spindle Type:		Cylindrical				
Spindle No.:		1				
Spindle Length:		7.493 cm				
Spindle Radius:		0.9421 cm				
RPM	Reading	Shear Stress	Shear Rate	Apparent Viscosity	Constants and Sums	
0.3	21.6	3.49	0.25	1377.89	N =	6.00
0.6	20.7	3.34	0.23	1454.92	H =	-0.69
1.5	23.6	3.80	0.31	1241.64	E =	10.99
3	43.3	6.98	1.18	589.52	n =	0.45
6	79.9	12.89	4.63	278.03	F =	4.94
12	90.6	14.60	6.12	238.51	l =	1.10
30					G =	0.79
60					k =	6.47

**FIG. 23: RHEOLOGICAL PROPERTIES**  
**Apparent Viscosity vs. Shear Rate**  
Hazen Research / Arsenic Removal Project



Material: Ferric Hydroxide Precipitate  
Ferric Source: Ferric Sulfate  
Thk U'Flow Solids Concentration: 2.60%



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION 6  
1445 ROSS AVENUE, SUITE 1200  
DALLAS, TX 75202-2733

SEP 3 1992

008633

**CERTIFIED MAIL: RETURN RECEIPT REQUESTED**

Mr. David Long, Esquire  
Southern Pacific Transportation Company  
Southern Pacific Building  
One Market Plaza  
San Francisco, CA 94105

Dear Mr. Long:

Please find enclosed an Administrative Order, Docket No. VI-15-92, addressing the Remedial Design/Remedial Action ("RD/RA") for the Crystal Chemical Company Superfund site ("Site"). This order requires that Southern Pacific Transportation Company implement the RD/RA for the soil remedy for the Site specified in the Amended Record of Decision signed June 16, 1992, and the RA for the ground water remedy for the Site specified in the Record of Decision signed September 27, 1990.

As set forth in Section XXVII (Opportunity to Confer) of the enclosed Administrative Order, Southern Pacific Transportation Company does have the opportunity to confer with EPA regarding the terms of the Order.

If you have any questions, please contact Lisa Marie Price of my staff at (214) 655-6735 or Michael C. Barra of the Office of Regional Counsel at (214) 655-2120.

Sincerely,

*Allyn M. Davis*

Allyn M. Davis  
Director  
Hazardous Waste Management Division

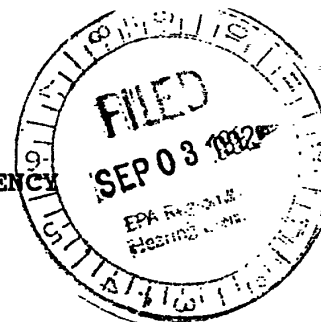
Enclosure

cc: Jesus Garza  
Executive Director  
Texas Water Commission

Charlotte Neitzel  
Holme, Roberts & Owen

Printed on Recycled Paper

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
Region 6



008634

In The Matter Of: )

Southern Pacific Transportation )  
Company )

RESPONDENT REGARDING THE )  
CRYSTAL CHEMICAL COMPANY SITE )  
Houston, Texas )

U.S. EPA  
Docket No. VI-15-92

Proceeding Under Section 106(a) of the )  
Comprehensive Environmental Response, )  
Compensation, and Liability Act of 1980 )  
as amended (42 U.S.C. § 9606(a)) )

ADMINISTRATIVE ORDER  
FOR REMEDIAL DESIGN AND REMEDIAL ACTION  
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008635

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
Region 6

In The Matter Of: )

Southern Pacific Transportation )  
Company )

RESPONDENT REGARDING THE )  
CRYSTAL CHEMICAL COMPANY SITE )  
Houston, Texas )

U.S. EPA  
Docket No. VI-15-92

Proceeding Under Section 106(a) of the )  
Comprehensive Environmental Response, )  
Compensation, and Liability Act of 1980 )  
as amended (42 U.S.C. § 9606(a)) )

ADMINISTRATIVE ORDER  
FOR REMEDIAL DESIGN AND REMEDIAL ACTION

I. INTRODUCTION AND JURISDICTION

1. This Order directs Respondent to perform a remedial design for the soil remedy described in the Amended Record of Decision ("Amended ROD") for the Crystal Chemical Company Site ("Site") dated June 16, 1992; to implement the design of the remedy for soil contamination prepared pursuant to this Order by performing the remedial actions for soil described in the Amended ROD; and to implement the design of the remedy for ground water contamination prepared pursuant to the Administrative Order on Consent for the Remedial Design (Ground Water Contamination), U.S. EPA Docket No. CERCLA 6-11-92 ("AOC"), by performing the remedial actions for ground water described in the Record of Decision ("ROD") for the Site dated September 27, 1990. This Order is issued to Respondent by the United States Environmental

Protection Agency ("EPA") under the authority vested in the President of the United States by Section 106(a) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended ("CERCLA"), 42 U.S.C. § 9606(a). This authority was delegated to the Administrator of EPA on January 23, 1987, by Executive Order 12580 (52 Fed. Reg. 2926, January 29, 1987), and was further delegated to EPA Regional Administrators on September 13, 1987, by EPA Delegation No. 14-14-B, and redelegated to the Director, Hazardous Waste Management Division, EPA Region 6 on November 3, 1988, by Region 6 Delegation No. R6-14-14-B.

## II. FINDINGS OF FACT

2. The Site is located at 3502 Rogerdale Road, in southwestern Houston, Harris County, Texas. The Crystal Chemical Company ("Crystal"), which produced arsenical, phenolic and amine-based herbicides from 1968 to 1981, operated on approximately 6.8 acres. The acreage is bounded on the west by the Harris County Flood Control Channel and lies immediately south of Westpark Drive. The Site is located east of the area of Harris County known as Alief.

3. While the Crystal Chemical Company was operating, four evaporation ponds, several structures, and many storage tanks existed on the Site. The Site is now fenced, and all above ground structures have been removed. The Site has also been capped and graded in order to promote drainage.

4. The Harris County Flood Control Channel bounds the Site on the west. Surface waters that enter the flood control channel flow south and are discharged into the Brays Bayou, approximately one mile south of the Site. Brays Bayou eventually drains into the Houston Ship Channel, which enters Scott Bay and eventually Galveston Bay. For a more complete description of the Site location, see the ROD and the Amended ROD which are included in this Order as Attachments 1 and 2, respectively.

5. Respondent Southern Pacific Transportation Company, formerly the Southern Pacific Company, ("Southern Pacific"), was, from at least about April 1969 until about June 1979, the owner of the land on which the Site is located. During that time, hazardous substances, including some or all of those described in this section, were disposed of at the Site.

a. Southern Pacific leased the Site to Crystal from April 1969 until July 1979, at which time Crystal exercised a purchase option in the lease and acquired the property subject to a deed of trust lien retained by Southern Pacific.

b. Southern Pacific operated a rail line adjacent to the Site, including a spur which served the Crystal plant, until September 1981, when Crystal ceased operations.

c. Southern Pacific currently owns property directly adjacent to the Crystal property on the east, which is contaminated with arsenic from the Site.

d. Southern Pacific is a Delaware corporation.

6. On September 9, 1983, (48 Fed. Reg. 175), pursuant to section 105 of CERCLA, 42 U.S.C. § 9605, EPA placed the Crystal Chemical Company Site on the National Priorities List, set forth at 40 C.F.R. Part 300, Appendix B.

7. From about May 4, 1983, to about June 15, 1984, the Texas Department of Water Resources ("TDWR"), pursuant to a cooperative agreement with EPA, undertook a remedial investigation and feasibility study ("RI/FS") for the Site pursuant to CERCLA and the National Contingency Plan ("NCP"), 40 C.F.R. Part 300.

8. Pursuant to section 117 of CERCLA, 42 U.S.C. § 9617, EPA published notice of the completion of the FS and of the proposed plan for remedial action on June 20, 1984, and provided opportunity for public comment on the proposed remedial action.

9. In response to public comment, EPA and TDWR undertook an Addendum Feasibility Study ("AFS"), which was completed about December 14, 1984.

10. Pursuant to section 117 of CERCLA, 42 U.S.C. § 9617, EPA published notice of the completion of the AFS and of the proposed plan for remedial action on April 19, 1985, and provided opportunity for public comment on the proposed remedial action.

11. Following the enactment of the Superfund Amendments and Reauthorization Act ("SARA") in October, 1986, EPA determined that a Supplemental Feasibility Study ("SFS") should be conducted for the Site.

12. From about April 3, 1987, to about December 15, 1990, Southern Pacific, under EPA oversight, began the SFS.

13. EPA completed the Draft Final SFS in May 1990. EPA completed the Final SFS in September 1990.

14. Pursuant to section 117 of CERCLA, 42 U.S.C. § 9617, EPA published notice of a proposed plan for remedial action in the *Houston Post* on May 27, 1990, and provided opportunity for public comment on the proposed remedial action from June 11, 1990, through July 11, 1990. A public meeting was held on June 21, 1990, at which EPA received oral comments from the public.

15. The ROD documenting the remedy selection for the arsenic-contaminated soils and for the contaminated ground water was signed on September 27, 1990. The ground water remedy that was selected in the ROD consists of extraction, treatment, and discharge to a Publicly Owned Treatment Works ("POTW"), to surface water, or reinjection. The soils remedy selected in the ROD includes excavating offsite soils contaminated with arsenic greater than 30 ppm, treating all soils contaminated with arsenic greater than 300 ppm with a process called In-Situ Vittrification, and capping the entire site after the soils treatment had been completed.

16. In July 1991, EPA was notified by the only vendor of the In-Situ Vittrification technology that the technology would be unavailable for an undetermined period of time because of the

need to do additional analytical and experimental work on the technology.

17. Pursuant to section 117 of CERCLA, 42 U.S.C. § 9617, EPA published notice of an amended proposed plan for soil remedial action in the **Houston Post** on February 12, 1992, and provided opportunity for public comment on the proposed remedial action from February 24, 1992, through March 24, 1992. A public meeting was held on March 19, 1992, at which EPA received oral comments from the public.

18. The Amended ROD documenting the remedy selection for the arsenic-contaminated soils was signed on June 16, 1992. The remedy selected in the Amended ROD consists of the excavation of offsite soils and sediments to a concentration of 30 ppm for arsenic, placement of these excavated soils on to the Site, and construction of a multi-layer cap over the entire site.

19. a. During the plant operations from 1968 to 1981, Crystal produced arsenic-based herbicides such as MSMA, along with a wide spectrum of phenolic- and amine-based herbicides (Dinitro General, Dinitro 3, Naptalam, Naptro, Dimethoate 267 and Crysthyon 2-L). These arsenic- and phenol-based products, along with the raw materials required for their production (e.g., arsenic trioxide, sodium arsenite, dinitrophenol) were major sources of the contamination at the Site.

b. Arsenic ranks twentieth (20th) in abundance among the natural elements in the Earth's crust and, therefore, is found

naturally occurring in rocks and soils. However, arsenic is a poisonous solid element which may be acutely toxic in doses from 10 to 300 milligrams ("mg") of arsenic per kilogram of body weight in humans, and is a Group A human carcinogen. Arsenic is a designated CERCLA hazardous substance at 40 C.F.R. § 302.4, a toxic pollutant at 40 C.F.R. § 401.15, and a characteristic hazardous waste at 40 C.F.R. § 261.24 (if when using the Toxicity Characteristic Leaching Procedure ("TCLP"), the concentration exceeds 5.0 parts per million). Additionally, a specific type of arsenic (i.e., K031 - by-product salts generated in the production of MSMA and cacodylic acid) is listed and regulated hazardous waste at 40 C.F.R. § 261.33.

20. a. During the years of operation, the Crystal production facilities were located on the southwestern portion of the Site. Dikes around the site perimeter were constructed to contain production wastewater and surface water run-off on the property. Surface water run-off and process wastewaters were diverted away from the process operations to four (4) unlined surface impoundments. Operation and maintenance problems at the Crystal facility during the late 1970's resulted in several violations of the Texas Water Commission ("TWC"), formerly the TDWR, environmental standards. A significant problem was repeated flooding of the Site which carried arsenic-contaminated wastewater across the Site and off the Site. Another source of contamination was the raw materials and finished products that



were stored onsite on the ground, both of which occasionally spilled and, therefore, leaked onto and into surface soils.

b. One of the more significant factors that contributed to the spread of arsenic-containing materials outside of the process areas and offsite was the periodic flooding of the Site due to poor site drainage and the Site's proximity to Harris County Flood Control Channel, D-124-00-00. In June 1976, an extended period of wet weather flooded the Site. The capacity of the dikes was exceeded and surface run-off from process and material storage areas flowed in a northerly direction toward the property line. The discharges led to litigation between the State of Texas and Crystal in December 1977. Initially, the perimeter dikes contained the water on the Site, however, sampling conducted during the Site Investigation ("SI") in 1984 and for the SFS indicated that water overflowed and seeped into adjacent drainage ditches. These drainage ditches discharge into Brays Bayou.

c. Airborne arsenic was released offsite during the plant's operation through aerosol drift from the mechanical aeration in the wastewater evaporation ponds, cooling tower drift and from wind blown dust. Crystal Chemical Company ceased operations in 1981. Subsequently, the entire Site was capped during the EPA Emergency Removal Action in 1983; therefore, the airborne arsenic release potential has been greatly reduced.

d. Both raw and finished containerized (e.g., drummed) materials were stored on the ground, in the open. These

materials occasionally spilled and, therefore, leaked onto and into surface soils. Arsenic trioxide was received in bulk from rail cars, and poor containment of the arsenic during loading and unloading operations was a frequent source of contamination.

e. The areal extent of soils and sediment contamination is estimated to cover approximately 24.4 acres, of which 6.8 acres was the site of the Crystal Chemical Company facility. The estimated volume of soils and sediments requiring remediation is approximately 156,000 cubic yards. There are approximately 3,000,000 gallons of arsenic-contaminated ground water associated with the Site. The ROD, Amended ROD, and the SFS contain more detailed discussions of the extent of contamination.

21. There is a potential for the contaminants at the Site to reach the public through a number of pathways. The routes with the most potential are ingestion of or direct contact with either onsite or offsite contaminated soils and sediments. The other pathways identified include ingestion of or direct contact with surface water or ground water, inhalation of ambient air and ingestion of contaminated crawfish.

22. a. Approximately 20,000 people live within a one-mile radius of the Site. The contaminated soil was determined to be a principal threat at the Site to human health, welfare or the environment because of direct contact, ingestion, and inhalation risks and because of the soil's impact on ground water. The remedial objectives for the soil are to eliminate potential

exposure via ingestion, inhalation or direct contact with contaminants and to reduce the potential for the soil to act as a continued source for surface water and ground water contamination.

b. The contaminated shallow ground water was also determined to be a principal problem at the Site because of the potential exposure of the public to the Site contaminants and because of the threat of migration of contaminants to deeper zones of ground water. The deeper ground water zones are used for industrial, irrigation, and drinking water purposes. The remedial objective is to reduce the amount of contamination to human health-based standards in order to eliminate or minimize the risks associated with the contaminated shallow ground water.

23. EPA initiated a number of Emergency Removal Actions between September 1981 and February 1983 to stabilize the Site. During the first EPA emergency cleanup, the wastewater was removed from the ponds and disposed of at an offsite commercial waste disposal facility. The top foot of soil was removed, mixed with lime, then deposited back into the wastewater ponds. A temporary cap, which included a plastic cover topped by a layer of clay, was placed over the area to limit the infiltration of water into contaminated soil. The arsenic trioxide was sold, and the buildings and process equipment were disassembled, decontaminated and sold, essentially leaving the Site vacant. The only remaining structures onsite are two concrete slabs. Subsequently, EPA has taken further measures to control surface

runoff and site access, and to enhance the integrity of the temporary cap. Steps taken by EPA in 1983 and 1988 included construction of drains, fencing, and placement of additional fill onsite.

24. a. The ROD calls for the extraction of approximately 3,000,000 gallons of contaminated ground water from water-bearing zones impacted by the Site, treatment of these contaminated waters to reduce arsenic contamination to the Maximum Contaminant Level ("MCL") for arsenic (0.05 ppm), and discharge to a POTW, to surface water, or reinjection of the treated water. The goal of the remedial action is to restore the ground water to a useable state, i.e., removing the arsenic to the MCL within the area of attainment for the Site.

b. The Amended ROD calls for the excavation of approximately 55,000 cubic yards of offsite soils and sediments contaminated with arsenic above 30 ppm, placement of these soils back onto the Site, and construction of a multi-layer cap over the entire Site.

25. The ROD and Amended ROD address the contaminated soils and the contaminated groundwater as one unit. The remedy for the soil contamination addresses the principal threats at the Site by eliminating potential exposure via ingestion, inhalation or direct contact with contaminants and by reducing the potential for the soil to act as a continued source for surface water and ground water contamination. The remedy for the ground water

contamination also addresses the principal threats by eliminating potential exposure via ingestion and direct contact with contaminants and by eliminating the potential for migration of contaminants to deeper zones of ground water.

### III. CONCLUSIONS OF LAW AND DETERMINATIONS

26. The Crystal Chemical Company Site is a "facility" as defined in section 101(9) of CERCLA, 42 U.S.C. § 9601(9).

27. Respondent is a "person" as defined in section 101(21) of CERCLA, 42 U.S.C. § 9601(21).

28. Respondent is a "liable party" as defined in section 107(a) of CERCLA, 42 U.S.C. § 9607(a), and is subject to this Order under section 106(a) of CERCLA, 42 U.S.C. § 9606(a).

29. The substances identified in paragraph 19 are found at the Site and are "hazardous substances" as defined in section 101(14) of CERCLA, 42 U.S.C. § 9601(14).

30. The hazardous substances identified in paragraph 19 have been and threaten to be released from the Site into the soil, groundwater, surface water, and air.

31. The past disposal and migration of hazardous substances from the Site are a "release" as defined in section 101(22) of CERCLA, 42 U.S.C. § 9601(22).

32. The potential for future migration of hazardous substances from the Site poses a threat of a "release" as defined in section 101(22) of CERCLA, 42 U.S.C. § 9601(22).

33. The release or threat of release of one or more hazardous substances from the Site may present an imminent and substantial endangerment to the public health or welfare or the environment.

34. The contamination and endangerment at this Site constitute an indivisible injury. The actions required by this Order are necessary to protect the public health, welfare, and the environment.

#### IV. NOTICE TO THE STATE

35. On September 2, 1992, prior to issuing this Order, EPA notified the State of Texas, Texas Water Commission, that EPA would be issuing this Order.

#### V. ORDER

36. Based on the foregoing, Respondent is hereby ordered, to comply with the following provisions, including but not limited to all attachments to this Order, all documents incorporated by reference into this Order, and all schedules and deadlines in this Order, attached to this Order, or incorporated by reference into this Order:

#### VI. DEFINITIONS

37. Unless otherwise expressly provided herein, terms used in this Order which are defined in CERCLA or in regulations

promulgated under CERCLA shall have the meaning assigned to them in the statute or its implementing regulations. Whenever terms listed below are used in this Order or in the documents attached to this Order or incorporated by reference into this Order, the following definitions shall apply:

a. "Amended Record of Decision" or "Amended ROD" shall mean the EPA Amended Record of Decision relating to the Site, signed on June 16, 1992 by the Regional Administrator, EPA Region 6, and all attachments thereto. A copy of the Amended ROD is attached hereto as Attachment 2.

b. "CERCLA" shall mean the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, 42 U.S.C. § 9601 et seq.

c. "Day" shall mean a calendar day unless expressly stated to be a working day. "Working day" shall mean a day other than a Saturday, Sunday, or Federal holiday. In computing any period of time under this Order, where the last day would fall on a Saturday, Sunday, or Federal holiday, the period shall run until the end of the next working day.

d. "EPA" shall mean the United States Environmental Protection Agency and any successor departments or agencies of the United States.

e. "National Contingency Plan" or "NCP" shall mean the National Contingency Plan promulgated pursuant to Section 105 of CERCLA, 42 U.S.C. § 9605, codified at 40 C.F.R. Part 300, including any amendments thereto.

f. "Operation and Maintenance" or "O&M" shall mean all activities required to maintain the effectiveness of the Remedial Action as required under the Operation and Maintenance Plan developed by Respondent pursuant to this Order and the Statement of Work ("SOW") and approved by EPA.

g. "Paragraph" shall mean a portion of this Order identified by an arabic numeral.

h. "Performance Standards" shall mean those remedial objectives, remediation goals, cleanup standards, standards of control, and other substantive requirements, criteria or limitations set forth in the ROD and Amended ROD or Section I of the SOW.

i. "Record of Decision" or "ROD" shall mean the EPA Record of Decision relating to the Site, signed on September 27, 1990 by the Regional Administrator, EPA Region 6, and all attachments thereto. A copy of the ROD is attached hereto as Attachment 1.

j. "Remedial Action" or "RA" shall mean those activities, except for Operation and Maintenance, to be undertaken by Respondent to implement the final plans and specifications submitted by Respondent pursuant to the Remedial Design Work Plans and Remedial Action Work Plans approved by EPA, including any additional activities required under Sections X (Failure to Attain Remedial Objectives), XI (EPA Periodic Review), XII (Additional Response Actions), XIII (Endangerment and Emergency Response), and XIV (EPA Review of Submissions) of this Order.



k. "Remedial Design" or "RD" shall mean those activities to be undertaken by Respondent to develop the final plans and specifications for the Remedial Action pursuant to the Remedial Design Work Plans.

l. "Section" shall mean a portion of this Order identified by a roman numeral and includes one or more paragraphs.

m. "Site" shall mean the Crystal Chemical Company Superfund site, located at 3502 Rogerdale Road in Houston, Harris County, Texas.

n. "State" shall mean the State of Texas.

o. "Statement of Work" or "SOW" shall mean the Statement of Work for the implementation of the Remedial Design, Remedial Action, and Operation and Maintenance at the Site attached hereto as Attachment 3, and any modifications thereto made pursuant to this Order.

p. "TWC" shall mean the Texas Water Commission.

q. "United States" shall mean the United States of America.

r. "Work" shall mean all activities Respondent is required to perform under this Order, including Remedial Design, Remedial Action, Operation and Maintenance, and any activities required to be undertaken pursuant to Sections VII (Notice of Intent to Comply) through XXIII (Assurance of Ability to Complete Work) of this Order.

## VII. NOTICE OF INTENT TO COMPLY

38. Respondent shall provide, not later than five (5) days after the effective date of this Order, written notice to EPA's Remedial Project Manager ("RPM") stating whether it will comply with the terms of this Order. If Respondent does not unequivocally commit to perform the Remedial Design and Remedial Action as provided by this Order, it shall be deemed to have violated this Order and to have failed or refused to comply with this Order. Respondent's written notice shall describe, using facts that exist on or prior to the effective date of this Order, any "sufficient cause" defenses asserted by Respondent under sections 106(b) and 107(c)(3) of CERCLA. The absence of a response by EPA to a notice required by this paragraph shall not be deemed to be acceptance of Respondent's assertions.

## VIII. PARTIES BOUND

39. This Order shall apply to and be binding upon Respondent, its directors, officers, employees, agents, successors, and assigns. Respondent is responsible for carrying out all activities required by this Order. No change in the ownership, corporate status, or other control of Respondent shall alter any of Respondent's responsibilities under this Order.

40. Respondent shall provide a copy of this Order to any prospective owners or successors before a controlling interest in Respondent's assets, property rights, or stock are transferred to the prospective owner or successor. Respondent shall provide a

copy of this Order to each contractor, sub-contractor, laboratory, or consultant retained to perform any Work under this Order, within five (5) days after the effective date of this Order or on the date such services are retained, whichever date occurs later. Respondent shall also provide a copy of this Order to each person representing Respondent with respect to the Site or the Work and shall condition all contracts and subcontracts entered into hereunder upon performance of the Work in conformity with the terms of this Order. With regard to the activities undertaken pursuant to this Order, each contractor and subcontractor shall be deemed to be related by contract to the Respondent within the meaning of section 107(b)(3) of CERCLA, 42 U.S.C. § 9607(b)(3). Notwithstanding the terms of any contract, Respondent is responsible for compliance with this Order and for ensuring that its contractors, subcontractors and agents comply with this Order, and perform any Work in accordance with this Order.

41. Within five (5) days after the effective date of this Order, Respondent, if Respondent owns real property comprising all or part of the Site shall record a copy or copies of this Order in the appropriate governmental office where land ownership and transfer records are filed or recorded, and shall ensure that the recording of this Order is indexed to the titles of each and every property at the Site so as to provide notice to third parties of the issuance and terms of this Order with respect to those properties. Respondent shall, within fifteen (15) days

after the effective date of this Order, send notice of such recording and indexing to EPA.

42. Not later than sixty (60) days prior to any transfer of any real property interest in any property included within the Site, Respondent shall submit a true and correct copy of the transfer document(s) to EPA, and shall identify the transferee by name, principal business address and effective date of the transfer.

#### IX. WORK TO BE PERFORMED

43. Respondent shall cooperate with EPA in providing information to the public regarding the Work. As requested by EPA, Respondent shall participate in the preparation of such information for distribution to the public and in public meetings which may be held or sponsored by EPA to explain activities at or relating to the Site.

44. All aspects of the Work to be performed by Respondent pursuant to Sections IX (Work To Be Performed), XI (EPA Periodic Review), XII (Additional Response Actions), and XVI (Quality Assurance, Sampling and Data Analysis) of this Order shall be under the direction and supervision of the Supervising Contractor, the selection of which shall be subject to disapproval by EPA. Within 30 days after the effective date of this Order, Respondent shall notify EPA in writing of the name, title, and qualifications of any contractor proposed to be the Supervising Contractor. The Supervising Contractor may assume the role of Project Coordinator, Remedial Designer, Remedial

Action Contractor, and Remedial Action Quality Assurance Official, however, the Supervising Contractor shall not assume both the role of Remedial Action Contractor and Remedial Action Quality Assurance Official. EPA will issue a notice of disapproval or an authorization to proceed. If at any time thereafter, Respondent proposes to change a Supervising Contractor, Respondent shall give such notice to EPA and must obtain an authorization to proceed from EPA before the new Supervising Contractor performs, directs, or supervises any Work under this Order.

45. If EPA disapproves a proposed Supervising Contractor, EPA will notify Respondent in writing. Respondent shall submit to EPA a list of contractors, including the qualifications of each contractor, that would be acceptable to them within 30 days of receipt of EPA's disapproval of the contractor previously proposed. EPA will provide written notice of the names of any contractor(s) that it disapproves and an authorization to proceed with respect to any of the other contractors. Respondent may select any contractor from that list that is not disapproved and shall notify EPA of the name of the contractor selected within 21 days of EPA's authorization to proceed.

46. All aspects of the Work to be performed by Respondent pursuant to this Order shall be under the direction and supervision of a qualified Project Coordinator, the selection of which shall be subject to disapproval by EPA. The Project

Coordinator may be a member of the Respondent's staff, an independent contractor, or a member of the Supervising Contractor's staff. Within thirty (30) days after the effective date of this Order, Respondent shall notify EPA in writing of the name and qualifications of the Project Coordinator, including primary support entities and staff, proposed to be used in carrying out Work under this Order. The Project Coordinator is to be used in carrying out the overall coordination and management of all activities required under this Order. The Project Coordinator shall not be an attorney for the Respondent in this matter. If at any time Respondent proposes to use a different Project Coordinator, Respondent shall notify EPA. The selection of a different Project Coordinator shall be subject to disapproval by EPA.

47. EPA will review Respondent's selection of a Project Coordinator according to the terms of this paragraph and Section XIV (EPA Review of Submissions) of this Order. If EPA disapproves of the selection of the Project Coordinator, Respondent shall submit to EPA within 30 days after receipt of EPA's disapproval of the Project Coordinator previously selected, a list of Project Coordinators, including primary support entities and staff, that would be acceptable to Respondent. EPA will thereafter provide written notice to Respondent of the names of the Project Coordinators that are acceptable to EPA. Respondent may then select any approved Project Coordinator from that list and shall notify EPA of the name of the Project

Coordinator selected within twenty-one (21) days of EPA's designation of approved Project Coordinators.

48. Respondent shall, prior to any off-site shipment of hazardous substances from the Site to an out-of-state waste management facility, provide written notification to the appropriate state environmental official in the receiving state and to EPA's RPM of such shipment of hazardous substances. However, the notification of shipments shall not apply to any off-Site shipments when the total volume of all shipments from the Site to the State will not exceed ten (10) cubic yards.

a. The notification shall be in writing, and shall include the following information: (1) the name and location of the facility to which the hazardous substances are to be shipped; (2) the type and quantity of the hazardous substances to be shipped; (3) the expected schedule for the shipment of the hazardous substances; and (4) the method of transportation. Respondent shall notify the receiving state of major changes in the shipment plan, such as a decision to ship the hazardous substances to another facility within the same state, or to a facility in another state.

b. The identity of the receiving facility and state will be determined by Respondent following the award of the contract for Remedial Action construction. Respondent shall provide all information, including information under the categories noted in paragraph 48.a above, on the off-Site shipments as soon as

practicable after the award of the contract and before the hazardous substances are actually shipped.

A. Remedial Design for Soil Remedy

49. a. Within thirty (30) days after Respondent selects an approved Project Coordinator and an approved Supervision Contractor, Respondent shall submit a work plan for the Remedial Design for the soil remedy at the Site ("Remedial Design (Soil) Work Plan" or "RD (Soil) Work Plan") to EPA for review and approval. The RD (Soil) Work Plan shall include a step-by-step plan for completing the remedial design for the soil remedy selected in the Amended ROD and for attaining and maintaining all requirements identified in the Amended ROD, including the remedial objectives of the remedial action for soil selected in the Amended ROD. The RD (Soil) Work Plan shall be prepared in accordance with the SOW, attached hereto as Attachment 3, and shall comport with EPA's "Superfund Remedial Design and Remedial Action Guidance, OSWER Directive 9355.0-4A".

b. The RD (Soil) Work Plan shall describe in detail the tasks and deliverables Respondent shall complete during the remedial design phase, and a schedule for completing the tasks and deliverables in the RD (Soil) Work Plan. The requirements of these deliverables and the tasks associated with the deliverables are more fully described in the attached SOW. The RD (Soil) Work Plan shall include, but not be limited to, plans and schedules for the completion of the following:



- 1) Health and Safety Plan;
- 2) Remedial Design Sampling and Analysis Plan;
- 3) Remedial Design Quality Assurance Project Plan ("RDQAPP");
- 4) Community Relations Plan;
- 5) Remedial Design Contingency Plan;
- 6) Preliminary Soil Design Submittal, to include but not limited to, the Off-Site Soil Sampling Results Report;
- 7) Intermediate Soil Design Submittal;
- 8) Pre-Final/Final Soil Design Submittal.

50. The RD (Soil) Work Plan shall be consistent with, and shall provide for implementing the soil remedy selected in the Amended ROD. Upon approval by EPA, the RD (Soil) Work Plan is incorporated into this Order as a requirement of this Order and shall be an enforceable part of this Order.

51. Upon approval of the RD (Soil) Work Plan by EPA, Respondent shall implement the RD (Soil) Work Plan according to the schedule in the approved RD (Soil) Work Plan. Any violation of the approved RD (Soil) Work Plan shall be a violation of this Order. Unless otherwise directed by EPA, Respondent shall not perform further Remedial Design activities at the Site prior to EPA's written approval of the RD (Soil) Work Plan, unless such work is being conducted pursuant to the AOC.

52. Upon approval by EPA, the Final Soil Design Submittal for the soils remedy is incorporated into this Order as a requirement of this Order and shall be an enforceable part of this Order.

B. Remedial Action for Soil Remedy

53. Not later than thirty (30) days after EPA approves the Final Soil Design submittal, Respondent shall submit a Remedial Action (Soil) Work Plan ("RA (Soil) Work Plan") to EPA for review and approval. The RA (Soil) Work Plan shall provide for implementation of the remedy, in accordance with the attached SOW, as set forth in the design plans and specifications in the approved Final Soil Design submittal.

54. The requirements of deliverables and tasks associated with the deliverables for the RA (Soil) Work Plan are more fully described in the attached SOW. The RA (Soil) Work Plan shall include, but not be limited to, methodologies, plans, and schedules for completion of the following:

- 1) selection of the Remedial Action contractor;
- 2) execution of the contract for completion of the Remedial Action;
- 3) schedule of Remedial Action activities, to include, but not limited to construction, operational and functional, and long-term remedial action phases;
- 4) identification of and satisfactory compliance with permitting requirements;
- 5) identification of the Remedial Action Project Team;

- 6) strategies and schedule for the implementation of plans previously prepared;
- 7) Transportation and Disposal Plan, pursuant to Paragraph 48 of the Order;
- 8) Annual Soil Remedial Action Report;
- 9) Pre-Final Soil Remedy Inspection;
- 10) Soil Remedial Action Report;
- 11) Certification of Soil Remedial Action; and
- 12) Completion of the Work.

55. Upon approval by EPA, the RA (Soil) Work Plan is incorporated into this Order as a requirement of this Order and shall be an enforceable part of this Order.

56. Upon approval of the RA (Soil) Work Plan by EPA, Respondent shall implement the activities required under the RA (Soil) Work Plan according to the schedules in the RA (Soil) Work Plan.

Unless otherwise directed by EPA, Respondent shall not commence Remedial Action for the soil remedy at the Site prior to approval of the RA (Soil) Work Plan.

57. Respondent shall notify EPA in writing prior to commencement of the Remedial Action for the soil remedy. The notification shall include, but not be limited to, the expected date of commencement of onsite activities, and a schedule of activities to be conducted.

58. The Work performed by Respondent pursuant to this Order shall, at a minimum, achieve the remedial objectives and remediation goals for the soil remedy specified in the Amended ROD.

59. Notwithstanding any action by EPA, Respondent remains fully responsible for achievement of the remedial objectives and remediation goals in the Amended ROD. Nothing in this Order, or in the Remedial Design for the soil remedy or RA (Soil) Work Plan, or EPA's approval of any other submission, shall be deemed to constitute a warranty or representation of any kind by EPA that full performance of the Remedial Design or Remedial Action will achieve the remedial objectives and remediation goals set forth in the Amended ROD. Respondent's compliance with such approved documents does not foreclose EPA from seeking additional work to achieve the applicable Performance Standards.

60. a. Within sixty (60) days after Respondent concludes that the Remedial Action for the soil remedy has been fully performed and the Performance Standards have been attained, Respondent shall so notify EPA in writing and shall schedule and conduct a pre-certification inspection to be attended by Respondent and EPA. If, after the pre-certification inspection, the Respondent still believes that the Remedial Action for the soil remedy has been fully performed and the Performance Standards have been attained, Respondent shall submit a written report within thirty (30) days of the inspection by a registered professional engineer

and Respondent's Project Coordinator certifying that the Remedial Action for the soil remedy has been completed in full satisfaction of the requirements of this Order. The written report shall include as-built drawings signed and stamped by a professional engineer. The report shall contain the following statement, signed by a responsible corporate official for the Respondent:

"To the best of my knowledge, after thorough investigation, I certify that the information contained in or accompanying this submission is true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

b. If, after completion of the pre-certification inspection and receipt and review of the written report, EPA determines that the Remedial Action for the soil remedy or any portion thereof has not been completed in accordance with this Order or that the Performance Standards have not been achieved, EPA shall notify Respondent in writing of the activities that must be undertaken to complete the Remedial Action for the soil remedy and shall set forth in the notice a schedule for performance of such activities. Respondent shall perform all activities described in the notice in accordance with the specifications and schedules established therein.

c. If EPA concludes, following the initial or any subsequent certification of completion by Respondent that the Remedial Action for the soil remedy has been fully performed in accordance with this Order, EPA may notify Respondent that the

Remedial Action for the soil remedy has been fully performed and that this notice shall constitute the Certification of Completion of the Remedial Action for the Soil Remedy. Certification of Completion of the Remedial Action for the Soil Remedy shall not affect Respondent's obligations under this Order. EPA's notification shall not limit EPA's right to perform periodic reviews pursuant to section 121(c) of CERCLA, 42 U.S.C. § 9621(c), or to take or require any action that in the judgment of EPA is appropriate at the Site, in accordance with 42 U.S.C. §§ 9604, 9606, or 9607.

C. Remedial Action for Ground Water Remedy

61. Upon approval by EPA, the Final Design Submittal for the ground water remedy prepared pursuant to the AOC is incorporated into this Order as a requirement of this Order and shall be an enforceable part of this Order.
62. Not later than thirty (30) days after EPA approves the Final Design submittal for the ground water remedy, Respondent shall submit a Remedial Action (Ground Water) Work Plan ("RA (Ground Water) Work Plan") to EPA for review and approval. The RA (Ground Water) Work Plan shall provide for implementation of the remedy, in accordance with the attached SOW, as set forth in the design plans and specifications in the approved Final Design submittal.
63. The requirements of deliverables and tasks associated with the deliverables for the RA (Ground Water) Work Plan are more

fully described in the attached SOW. The RA (Ground Water) Work Plan shall include methodologies, plans, and schedules for completion of, but not limited to the following:

- 1) selection of the Remedial Action contractor;
- 2) execution of the contract for completion of the Remedial Action;
- 3) schedule of RA activities, to include, but not limited to construction, operational and functional, and long-term remedial action phases;
- 4) identification of and satisfactory compliance with permitting requirements;
- 5) identification of the Remedial Action Project Team;
- 6) strategies and schedule for the implementation of plans previously prepared;
- 7) Transportation and Disposal Plan, pursuant to Paragraph 48 of the Order;
- 8) Annual Ground Water Remedial Action Report;
- 9) Ground Water Extraction Evaluation Report;
- 10) Pre-Final Ground Water Remedy Inspection;
- 11) Ground Water Remedial Action Report;
- 12) Certification of Ground Water Remedial Action; and
- 13) Completion of the Work.

64. Upon approval by EPA, the RA (Ground Water) Plan is incorporated into this Order as a requirement of this Order and shall be an enforceable part of this Order.

65. Upon approval of the RA (Ground Water) Work Plan by EPA, Respondent shall implement the activities required under the RA (Ground Water) Work Plan according to the schedules in the RA (Ground Water) Work Plan. Unless otherwise directed by EPA, Respondent shall not commence Remedial Action for the ground water remedy at the Site prior to approval of the RA (Ground Water) Work Plan.

66. Respondent shall notify EPA in writing prior to commencement of the Remedial Action for the ground water remedy. The notification shall include, but not be limited to, the expected date of commencement of onsite activities, and a schedule of activities to be conducted.

67. The Work performed by Respondent pursuant to this Order shall, at a minimum, achieve the remedial objectives and remediation goals for the ground water remedy specified in the ROD.

68. Notwithstanding any action by EPA, Respondent remains fully responsible for achievement of the remedial objectives and remediation goals in the ROD. Nothing in this Order, or in the Remedial Design for the ground water remedy or RA (Ground Water) Work Plan, or EPA's approval of any other submission, shall be deemed to constitute a warranty or representation of any kind by EPA that full performance of the Remedial Design or Remedial Action will achieve the remedial objectives and remediation goals set forth in the ROD. Respondent's compliance with such approved



documents does not foreclose EPA from seeking additional work to achieve the applicable Performance Standards.

69. a. Within sixty (60) days after Respondent concludes that the Remedial Action for the ground water remedy has been fully performed and the Performance Standards have been attained, Respondent shall so notify EPA in writing and shall schedule and conduct a pre-certification inspection to be attended by Respondent and EPA. If, after the pre-certification inspection, the Respondent still believes that the Remedial Action for the ground water remedy has been fully performed and the Performance Standards have been attained, Respondent shall submit a written report within thirty (30) days of the inspection by a registered professional engineer and Respondent's Project Coordinator certifying that the Remedial Action for the ground water remedy has been completed in full satisfaction of the requirements of this Order. The written report shall include as-built drawings signed and stamped by a professional engineer. The report shall contain the following statement, signed by a responsible corporate official for the Respondent:

"To the best of my knowledge, after thorough investigation, I certify that the information contained in or accompanying this submission is true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

b. If, after completion of the pre-certification inspection and receipt and review of the written report, EPA

determines that the Remedial Action for the ground water remedy or any portion thereof has not been completed in accordance with this Order or that the Performance Standards have not been achieved, EPA shall notify Respondent in writing of the activities that must be undertaken to complete the Remedial Action for the ground water remedy and shall set forth in the notice a schedule for performance of such activities. Respondent shall perform all activities described in the notice in accordance with the specifications and schedules established therein.

c. If EPA concludes, following the initial or any subsequent certification of completion by Respondent that the Remedial Action for the ground water remedy has been fully performed in accordance with this Order, EPA may notify Respondent that the Remedial Action for the ground water remedy has been fully performed and that this notice shall constitute the Certification of Completion of the Remedial Action for the Ground Water Remedy. Certification of Completion of the Remedial Action for the Ground Water Remedy shall not affect Respondent's obligation under this Order. EPA's notification shall not limit EPA's right to perform periodic reviews pursuant to section 121(c) of CERCLA, 42 U.S.C. § 9621(c), or to take or require any action that in the judgment of EPA is appropriate at the Site, in accordance with 42 U.S.C. §§ 9604, 9606, or 9607.

D. Completion of Work

70. a. Within sixty (60) days after Respondent concludes that all phases of the Work (including O & M), have been fully performed, Respondent shall schedule and conduct a pre-certification inspection to be attended by Respondent and EPA. If, after the pre-certification inspection, Respondent still believes that the Work has been fully performed, Respondent shall submit a written report by a registered professional engineer stating that the Work has been completed in full satisfaction of the requirements of this Order. The report shall contain the following statement, signed by a responsible corporate official for Respondent:

"To the best of my knowledge, after thorough investigation, I certify that the information contained in or accompanying this submission is true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

b. If, after review of the written report, EPA determines that any portion of the Work has not been completed in accordance with this Consent Decree, EPA will notify Respondent in writing of the activities that must be undertaken to complete the Work. EPA will set forth in the notice a schedule for performance of such activities consistent with the Order. Respondent shall perform all activities described in the notice in accordance with the specifications and schedules established therein.

c. If EPA concludes, based on the initial or any subsequent request for Certification of Completion by Respondent

that the Work has been fully performed in accordance with this Consent Decree, EPA may so notify the Respondent in writing. EPA's notification shall not limit EPA's right to perform periodic reviews pursuant to section 121(c) of CERCLA, 42 U.S.C. § 9621(c), or to take or require any action that in the judgment of EPA is appropriate at the Site, in accordance with 42 U.S.C. §§ 9604, 9606, or 9607.

#### X. FAILURE TO ATTAIN PERFORMANCE STANDARDS

71. In the event that EPA determines that additional response activities are necessary to meet the Performance Standards, EPA may notify Respondent that additional response actions are necessary.

72. Unless otherwise stated in writing by EPA, within thirty (30) days of receipt of notice from EPA that additional response activities are necessary to meet any of the Performance Standards, Respondent shall submit for approval by EPA a work plan for the additional response activities. The plan shall conform to the applicable requirements of sections IX (Work to be Performed), XVI (Quality Assurance, Sampling and Data Analysis), and XVII (Compliance with Applicable Laws) of this Order. Upon EPA's approval of the plan pursuant to Section XIV (EPA Review of Submissions), Respondent shall implement the plan for additional response activities in accordance with the provisions and schedule contained therein.

#### XI. EPA PERIODIC REVIEW

73. Under section 121(c) of CERCLA, 42 U.S.C. § 9621(c), and any applicable regulations, EPA may review the Site to assure that the Work performed pursuant to this Order adequately protects human health and the environment. Until such time as EPA certifies completion of the Work, Respondent shall conduct the requisite studies, investigations, or other response actions as determined necessary by EPA in order to permit EPA to conduct the review under section 121(c) of CERCLA. As a result of any review performed under this paragraph, Respondent may be required to perform additional Work or to modify Work previously performed.

#### XII. ADDITIONAL RESPONSE ACTIONS

74. EPA may determine that in addition to the Work identified in this Order and attachments to this Order, additional response activities may be necessary to protect human health and the environment. If EPA determines that additional response activities are necessary, EPA may require Respondent to submit a work plan for additional response activities. EPA may also require Respondent to modify any plan, design, or other deliverable required by this Order, including any approved modifications.

75. Not later than thirty (30) days after receiving EPA's notice that additional response activities are required pursuant to this Section, Respondent shall submit a work plan for the response activities to EPA for review and approval. Upon approval by EPA,

the work plan is incorporated into this Order as a requirement of this Order and shall be an enforceable part of this Order. Upon approval of the work plan by EPA, Respondent shall implement the work plan according to the standards, specifications, and schedule in the approved work plan. Respondent shall notify EPA of its intent to perform such additional response activities within seven (7) days after receipt of EPA's request for additional response activities.

#### XIII. ENDANGERMENT AND EMERGENCY RESPONSE

76. In the event of any action or occurrence during the performance of the Work which causes or threatens to cause a release of a hazardous substance or which may present an immediate threat to public health or welfare or the environment, Respondent shall immediately take all appropriate action to prevent, abate, or minimize the threat, and shall immediately notify EPA's RPM or, if the RPM is unavailable, EPA's Alternate RPM. If neither of these persons is available, Respondent shall notify the EPA Emergency Response Branch, Region 6. Respondent shall take such action in consultation with EPA's RPM and in accordance with all applicable provisions of this Order, including but not limited to the Health and Safety Plans and the Contingency Plans.

77. Nothing in the preceding paragraph shall be deemed to limit any authority of the United States to take, direct, or order all appropriate action to protect human health and the environment or

to prevent, abate, or minimize an actual or threatened release of hazardous substances on, at, or from the Site.

#### XIV. EPA REVIEW OF SUBMISSIONS

78. In all instances in which this Order requires written submittals of any kind to EPA, (other than monthly progress reports described in Section XV (Reporting Requirements), paragraphs 82 and 83), the report must be accompanied by the following certification signed by a "responsible official":

"I certify that the information contained in or accompanying this submission is true, accurate and complete. As to those identified portions of this submission for which I cannot personally verify the truth and accuracy, I certify as the company official having supervisory responsibility for the person(s) who, acting under my direct instructions, made the verification, that this information is true, accurate, and complete."

For the purpose of this certification, a "responsible official" of a corporation means a president, secretary, treasurer or vice-president of the corporation in charge of a principal business function, or any other person who performs similar decision-making functions for the corporation.

79. After review of any deliverable, plan, report or other item which is required to be submitted for review and approval pursuant to this Order EPA may: (a) approve the submission; (b) approve the submission with modifications to be made by Respondent; (c) disapprove the submission and direct Respondent to re-submit the document after incorporating EPA's comments to

EPA's satisfaction; or (d) disapprove the submission and assume responsibility for performing all or any part of the response action. As used in this Order, the terms "approval by EPA," "EPA approval," or a similar term means the action described in (a) or (b) of this paragraph. In the event of approval or approval with modifications, Respondent shall proceed to take any action required by the plan, report, or other item, as approved or modified.

80. Upon receipt of a notice of disapproval pursuant to paragraph 79(c) or an approval with a request for a modification pursuant to paragraph 79(b), Respondent shall, within fourteen (14) days or such other time as specified by EPA in its written notice of disapproval or request for modification, correct the deficiencies and resubmit the plan, report, or other item for approval. Notwithstanding the notice of disapproval, or approval with modifications, Respondent shall proceed, at the direction of EPA, to take any action required by any non-deficient portion of the submission.

81. If any submission is not approved by EPA, Respondent shall be deemed to be in violation of this Order.

#### XV. REPORTING REQUIREMENTS

82. In addition to any other requirement of this Order, Respondent shall submit to EPA three (3) copies of written monthly progress reports that: (a) describe the actions which have been taken toward achieving compliance with this Order



during the previous month; (b) include a summary of all results of sampling and tests and all other data received or generated by Respondent or its contractors or agents in the previous month; (c) identify all work plans, plans and other deliverables required by this Order completed and submitted during the previous month; (d) describe all actions, including, but not limited to, data collection and implementation of work plans, which are scheduled for the next two (2) months and provide other information relating to the progress of construction, including, but not limited to, critical path diagrams, Gantt charts and Pert charts; (e) include information regarding percentage of completion, unresolved delays encountered or anticipated that may affect the future schedule for implementation of the Work, and a description of efforts made to mitigate those delays or anticipated delays; (f) include any modifications to the work plans or other schedules that Respondent has proposed to EPA or that have been approved by EPA; and (g) describe all activities undertaken in support of the Community Relations Plan during the previous month and those to be undertaken in the next two (2) months. Respondent shall submit these progress reports to EPA by the tenth day of every month following the effective date of this Order until EPA notifies the Respondent pursuant to Paragraphs 60.c and 69.c of Section IX (Work to Be Performed). If requested by EPA, Respondent shall also provide briefings for EPA to discuss the progress of the Work.

83. Respondent shall notify EPA of any change in the schedule described in the monthly progress report for the performance of any activity, including, but not limited to, data collection and implementation of work plans, no later than seven (7) days prior to the performance of the activity.

84. Respondent shall submit three (3) copies of all plans, reports, and data required by the attached SOW, the Remedial Design (Soil) Work Plan, the Remedial Action Work Plans (both soil and ground water), or any other approved plans to EPA in accordance with the schedules set forth in such plans. Respondent shall simultaneously submit two (2) copies of all such plans, reports and data to the TWC.

#### XVI. QUALITY ASSURANCE, SAMPLING AND DATA ANALYSIS

85. Respondent shall use the quality assurance, quality control, and chain of custody procedures described in the "EPA NEIC Policies and Procedures Manual," May 1978, revised May 1986, EPA-330/9-78-001-R, EPA's "Guidelines and Specifications for Preparing Quality Assurance Program Documentation," June 1, 1987, EPA's "Data Quality Objective Guidance," (EPA/540/G87/003 and 004), and any amendments to these documents, while conducting all sample collection and analysis activities required herein by any plan. To provide quality assurance and maintain quality control, Respondent shall:

- a. Use only laboratories which have a documented Quality Assurance Program that complies with EPA guidance document QAMS-005/80.

- b. Ensure that the laboratory used by the Respondent for analyses, performs according to a method or methods deemed satisfactory to EPA and submits all protocols to be used for analyses to EPA at least 30 days before beginning analysis.
- c. Ensure that EPA personnel and EPA's authorized representatives are allowed access to the laboratory and personnel utilized by the Respondent for analyses.

86. Respondent shall notify EPA in writing not less than thirty (30) days in advance of any sample collection activity. At the request of EPA, Respondent shall allow split or duplicate samples to be taken by EPA or its authorized representatives, of any samples collected by Respondent with regard to the Site or pursuant to the implementation of this Order. In addition, EPA shall have the right to take any additional samples that EPA deems necessary.

#### XVII. COMPLIANCE WITH APPLICABLE LAWS

87. All activities by Respondent pursuant to this Order shall be performed in accordance with the requirements of all Federal and state laws and regulations. EPA has determined that the activities required by this Order are consistent with the NCP if they are performed in compliance with this Order.

88. Except as provided in section 121(e) of CERCLA and the NCP, no permit shall be required for any portion of the Work conducted on-site. The term "on-site" means the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response

action. Where any portion of the Work requires a Federal or state permit or approval, Respondent shall submit timely applications and take all other actions necessary to obtain and to comply with all such permits or approvals.

89. This Order is not, and shall not be construed to be, a permit issued pursuant to any Federal or state statute or regulation.

90. All materials removed from the Site shall be disposed of or treated at a facility approved by EPA's RPM and in accordance with section 121(d)(3) of CERCLA, 42 U.S.C. § 9621(d)(3); with the U.S. EPA "Revised Off-Site policy," OSWER Directive 9834.11, November 13, 1987; and with all other applicable Federal, state, and local requirements.

#### XVIII. REMEDIAL PROJECT MANAGER

91. All communications, whether written or oral, from Respondent to EPA shall be directed to EPA's RPM or Alternate RPM.

Respondent shall submit to EPA three (3) copies of all documents, including plans, reports, and other correspondence, which are developed pursuant to this Order, and shall send these documents by certified mail, return receipt requested, or by a reputable overnight delivery service with a receipt for delivery.

EPA's RPM is:

Lisa Marie Price  
Remedial Project Manager  
Superfund Texas Enforcement Section (6H-ET)  
1445 Ross Avenue  
Dallas, Texas 75202-2733

EPA's Alternate RPM is:

Stan Hitt  
Superfund Texas Enforcement Section (6H-ET)  
1445 Ross Avenue  
Dallas, Texas 75202-2733

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92. EPA has the unreviewable right to change its RPM or Alternate RPM. If EPA changes its RPM or Alternate RPM, EPA will inform Respondent in writing of the name, address, and telephone number of the new RPM or Alternate RPM.

93. EPA's RPM and Alternate RPM shall have the authority lawfully vested in RPMs and On-Scene Coordinators by the NCP, 40 C.F.R. Part 300. EPA's RPM or Alternate RPM shall have authority, consistent with the NCP, to halt any work at the Site, and to take any necessary response action. EPA's RPM and Alternate RPM shall have the authority to call such meetings with the Respondent and its representatives as EPA's RPM or Alternate RPM determine necessary to discuss the Respondent's performance of the requirements of this Order.

#### XIX. ACCESS TO SITE NOT OWNED BY RESPONDENT

94. If the Site, the off-site area that is to be used for access, property where documents required to be prepared or maintained by this Order are located, or other property subject to or affected by the remediation, is owned in whole or in part by parties other than those bound by this Order, Respondent will obtain, or use its best efforts to obtain, site access agreements from the present owners within sixty (60) days of the effective

date of this Order. Such agreements shall provide access for EPA, its contractors and oversight officials, the state and its contractors, and Respondent or Respondent's authorized representatives and contractors, and such agreements shall specify that Respondent is not EPA's representative with respect to liability associated with Site activities. Respondent shall save and hold harmless the United States and its officials, agents, employees, contractors, subcontractors, or representatives for or from any and all claims or causes of action or other costs incurred by the United States including but not limited to attorneys fees and other expenses of litigation and settlement arising from or on account of acts or omissions of Respondent, its officers, directors, employees, agents, contractors, subcontractors, and any persons acting on their behalf or under their control, in carrying out activities pursuant to this Order, including any claims arising from any designation of Respondent as EPA's authorized representative under section 104(e) of CERCLA. Copies of such agreements shall be provided to EPA prior to Respondent's initiation of field activities. Respondent's best efforts shall include providing reasonable compensation to any off-site property owner. If access agreements are not obtained within the time referenced above, Respondent shall immediately notify EPA of its failure to obtain access and its efforts to obtain access. Subject to the United States' non-reviewable discretion, EPA may use its legal authorities to obtain access for the Respondent, may perform

those response actions with EPA contractors at the property in question, or may terminate the Order if Respondent cannot obtain access agreements. If EPA performs those tasks or activities with contractors and does not terminate the Order, Respondent shall perform all other activities not requiring access to that property. Respondent shall integrate the results of any such tasks undertaken by EPA into its reports and deliverables.

#### XX. SITE ACCESS AND DATA/DOCUMENT AVAILABILITY

95. Respondent shall allow EPA and its authorized representatives and contractors to enter and freely move about all property at the Site and off-site areas subject to or affected by the Work under this Order or where documents required to be prepared or maintained by this Order are located, for the purposes of inspecting conditions, activities, the results of activities, records, operating logs, and contracts related to the Site or Respondent and its representatives or contractors pursuant to this Order; reviewing the progress of the Respondent in carrying out the terms of this Order; conducting tests as EPA or its authorized representatives or contractors deem necessary; using a camera, sound recording device or other documentary type equipment; and verifying the data submitted to EPA by Respondent. Respondent shall allow EPA and its authorized representatives to enter the Site, to inspect and copy all records, files, photographs, documents, sampling and monitoring data, and other writings related to work undertaken in carrying out this Order.

Nothing herein shall be interpreted as limiting or affecting EPA's right of entry or inspection authority under Federal law.

96. Respondent may assert a claim of business confidentiality covering part or all of the information submitted to EPA pursuant to the terms of this Order under 40 C.F.R. § 2.203, provided such claim is not inconsistent with section 104(e)(7) of CERCLA, 42 U.S.C. § 9604(e)(7) or other provisions of law. This claim shall be asserted in the manner described by 40 C.F.R. § 2.203(b) and substantiated by Respondent at the time the claim is made.

Information determined to be confidential by EPA will be given the protection specified in 40 C.F.R. Part 2. If no such claim accompanies the information when it is submitted to EPA, it may be made available to the public by EPA or the State without further notice to the Respondent. Respondent shall not assert confidentiality claims with respect to any data related to Site conditions, sampling, or monitoring.

97. Respondent shall maintain, for the period during which this Order is in effect, an index of documents that Respondent claims contain confidential business information. The index shall contain, for each document, the date, author, addressee, and subject of the document. Upon written request from EPA, Respondent shall submit a copy of the index to EPA.

#### XXI. RECORD PRESERVATION

98. Respondent shall provide to EPA upon request, copies of all documents and information within its possession and/or control or



that of its contractors or agents relating to activities at the Site or to the implementation of this Order, including but not limited to sampling, analysis, chain of custody records, manifests, trucking logs, receipts, reports, sample traffic routing, correspondence, or other documents or information related to the Work. Respondent shall also make available to EPA for purposes of investigation, information gathering, or testimony, its employees, agents, or representatives with knowledge of relevant facts concerning the performance of the Work.

99. Until ten (10) years after EPA provides notice pursuant to Section IX (Work to be Performed), Subsection D (Completion of Work), Respondent shall preserve and retain all records and documents in its possession or control, including the documents in the possession or control of its contractors and agents on and after the effective date of this Order, that relate in any manner to the Site. At the conclusion of this document retention period, Respondent shall notify the United States at least ninety (90) calendar days prior to the destruction of any such records or documents, and upon request by the United States, Respondent shall deliver any such records or documents to EPA.

100. Until ten (10) years after EPA provides notice pursuant to Section IX (Work to be Performed), Subsection D (Completion of Work), of this Order, Respondent shall preserve, and shall instruct its contractors and agents to preserve, all documents,

records, and information of whatever kind, nature or description relating to the performance of the Work. Upon the conclusion of this document retention period, Respondent shall notify the United States at least ninety (90) days prior to the destruction of any such records, documents or information, and, upon request of the United States, Respondent shall deliver all such documents, records and information to EPA.

101. Within fifteen (15) days after the effective date of this Order, Respondent shall submit a written certification to EPA's RPM that it has not altered, mutilated, discarded, destroyed or otherwise disposed of any records, documents or other information relating to its potential liability with regard to the Site since notification of potential liability by the United States or the State or the filing of suit against it regarding the Site. Respondent shall not dispose of any such documents without prior approval by EPA. Respondent shall, upon EPA's request and at no cost to EPA, deliver the documents or copies of the documents to EPA.

#### XXII. DELAY IN PERFORMANCE

102. Any delay in performance of this Order that, in EPA's judgment, is not properly justified by Respondent under the terms of this paragraph shall be considered a violation of this Order. Any delay in performance of this Order shall not affect Respondent's obligations to fully perform all obligations under the terms and conditions of this Order.

103. Respondent shall notify EPA of any delay or anticipated delay in performing any requirement of this Order. Such notification shall be made by telephone to EPA's RPM or Alternate RPM within forty-eight (48) hours after Respondent first knew or should have known that a delay might occur. Respondent shall adopt all reasonable measures to avoid or minimize any such delay. Within five (5) business days after notifying EPA by telephone, Respondent shall provide written notification fully describing the nature of the delay, any justification for delay, any reason why Respondent should not be held strictly accountable for failing to comply with any relevant requirements of this Order, the measures planned and taken to minimize the delay, and a schedule for implementing the measures that will be taken to mitigate the effect of the delay. Increased costs or expenses associated with implementation of the activities called for in this Order is not a justification for any delay in performance.

#### XXIII. ASSURANCE OF ABILITY TO COMPLETE WORK

104. Respondent shall demonstrate its ability to complete the Work required by this Order and to pay all claims that arise from the performance of the Work by obtaining and presenting to EPA within thirty (30) days after approval of the RD (Soil) Work Plan, one of the following: (1) a performance bond; (2) a letter of credit; (3) a guarantee by a third party; or (4) internal financial information to allow EPA to determine that Respondent has sufficient assets available to perform the Work. Respondent shall demonstrate financial assurance in an amount no less than

the estimate of cost for the remedial design and remedial action contained in the ROD and the Amended ROD for the Site. If Respondent seeks to demonstrate ability to complete the remedial action by means of internal financial information, or by guarantee of a third party, it shall re-submit such information annually, on the anniversary of the effective date of this Order. If EPA determines that such financial information is inadequate, Respondent shall, within thirty (30) days after receipt of EPA's notice of determination, obtain and present to EPA for approval one of the other three forms of financial assurance listed above.

105. At least fourteen (14) days prior to commencing any work at the Site pursuant to this Order, Respondent shall submit to EPA a certification that Respondent or its contractors and subcontractors have adequate insurance coverage or have indemnification for liabilities for injuries or damages to persons or property which may result from the activities to be conducted by or on behalf of Respondent pursuant to this Order. Respondent shall ensure that such insurance or indemnification is maintained for the duration of the Work required by this Order.

#### XXIV. UNITED STATES NOT LIABLE

106. The United States, by issuance of this Order, assumes no liability for any injuries or damages to persons or property resulting from acts or omissions by Respondent, or its directors, officers, employees, agents, representatives, successors, assigns, contractors, or consultants in carrying out any action

or activity pursuant to this Order. Neither EPA nor the United States may be deemed to be a party to any contract entered into by Respondent or its directors, officers, employees, agents, successors, assigns, contractors, or consultants in carrying out any action or activity pursuant to this Order.

#### XXV. ENFORCEMENT AND RESERVATIONS

107. EPA reserves the right to bring an action against Respondent under section 107 of CERCLA, 42 U.S.C. § 9607, for recovery of any response costs incurred by the United States related to this Order and not reimbursed by Respondent. This reservation shall include but not be limited to past costs, direct costs, indirect costs, the costs of oversight, the costs of compiling the cost documentation to support oversight cost demands, as well as accrued interest as provided in section 107(a) of CERCLA.

108. Notwithstanding any other provision of this Order, at any time during the response action, EPA may perform its own studies, complete the response action (or any portion of the response action) as provided in CERCLA and the NCP, and seek reimbursement from Respondent for its costs, or seek any other appropriate relief.

109. Nothing in this Order shall preclude EPA from taking any additional enforcement actions, including modification of this Order or issuance of additional Orders, and/or additional remedial or removal actions as EPA may deem necessary, or from requiring Respondent in the future to perform additional

activities pursuant to CERCLA, 42 U.S.C. § 9606(a), et seq., or any other applicable law. Respondent shall be liable under CERCLA section 107(a), 42 U.S.C. § 9607(a), for the costs of any such additional actions.

110. Notwithstanding any provision of this Order, the United States hereby retains all of its information gathering, inspection and enforcement authorities and rights under CERCLA or any other statutes or regulations.

111. Respondent shall be subject to civil penalties under section 106(b) of CERCLA, 42 U.S.C. § 9606(b), of not more than \$25,000 for each day in which Respondent willfully violates, or fails or refuses to comply with this Order without sufficient cause. In addition, failure to properly provide response action under this Order, or any portion hereof, without sufficient cause, may result in liability under section 107(c)(3) of CERCLA, 42 U.S.C. § 9607(c)(3), for punitive damages in an amount at least equal to, and not more than three times the amount of any costs incurred by the Hazardous Substances Superfund as a result of such failure to take proper action.

112. Nothing in this Order shall constitute or be construed as a release from any claim, cause of action or demand in law or equity against any person for any liability it may have arising out of or relating in any way to the Site.

113. If a court issues an order that invalidates any provision of this Order or finds that Respondent has sufficient cause not to comply with one or more provisions of this Order, Respondent shall remain bound to comply with all provisions of this Order not invalidated by the court's order.

XXVI. EFFECTIVE DATE AND COMPUTATION OF TIME

114. This Order shall be effective fifteen (15) days after the Order is signed by the Director, Hazardous Waste Management Division. All times for performance of ordered activities shall be calculated from this effective date.

XXVII. OPPORTUNITY TO CONFER

115. Respondent may, within seven (7) days after the date this Order is signed, request a conference with EPA to discuss this Order. If requested, the conference shall occur on September 10, 1992 at EPA Region 6, 1445 Ross Avenue, Dallas, Texas 75202.

116. The purpose and scope of the conference shall be limited to issues involving the implementation of the response actions required by this Order and the extent to which Respondent intends to comply with this Order. This conference is not an evidentiary hearing, and does not constitute a proceeding to challenge this Order. It does not give Respondent a right to seek review of this Order, or to seek resolution of potential liability, and no official stenographic record of the conference will be made. At any conference held pursuant to Respondent's request, Respondent may appear in person or by an attorney or other representative.

117. Requests for a conference must be by telephone followed by written confirmation mailed that day to:

Lisa Marie Price  
Remedial Project Manager  
Superfund Texas Enforcement Section (6H-ET)  
1445 Ross Avenue  
Dallas, Texas 75202-2733  
(214) 655-6735

So Ordered, this 3rd day of September, 1992.

BY: Allyn M. Davis  
Allyn M. Davis, Director  
Hazardous Waste Management Division  
U.S. Environmental Protection Agency  
Region 6



**STATEMENT OF WORK  
REMEDIAL DESIGN/REMEDIAL ACTION  
UNILATERAL ADMINISTRATIVE ORDER  
CRYSTAL CHEMICAL COMPANY SITE  
HOUSTON, TEXAS**

008691

**I. INTRODUCTION**

This Statement of Work ("SOW") sets forth the requirements for implementation of the Remedial Design for the soil remedy selected in the 1992 Amended Record of Decision, the Remedial Actions for the soil remedy and for the ground water remedy selected in the 1990 Record of Decision, and Operation and Maintenance at the Crystal Chemical Company site ("Crystal Chemical site" or "site"), as defined in Section VI (DEFINITIONS) of the Unilateral Administrative Order ("Order").

**A. PERFORMANCE STANDARDS**

The Performance Standards for the Remedial Action shall include remediation goals, remedial objectives and other substantive requirements, criteria, or limitations set forth in the ROD and Amended ROD, and as that term is defined in this Order. The Performance Standards for the ground water remedy shall be found in the Remediation Goals of Summary of Site Risks section (Section V. Summary of Site Risks, page 57 through page 60) and in the Selected Remedy section (Section IX. Selected Remedy, page 94 through 97) of the 1990 ROD (Attachment 1). The remedial objective for the ground water is to reduce the amount of contamination to human-health based standards in order to eliminate or minimize the risks associated with the contaminated shallow ground water. The remediation goal for the ground water is the Maximum Contaminant Level ("MCL") for arsenic, 0.05 parts per million.

The Performance Standards for the soil remedy shall be found in the Summary of Site Risks section (Section IV. Summary of Site Risks, pages 5 and 6) and in the Selected Remedy section (Section VIII. Selected Remedy, pages 21 through page 22) of the Amended ROD (Attachment 2). The remedial objectives for the soil are to eliminate potential exposure via ingestion, inhalation or direct contact with contaminants and by reducing the potential for the soil to act as a continued source for surface water and ground water contamination. The remediation goal for the soils is the removal of offsite soils to a concentration of 30 parts per million.

The above Performance Standards shall be used to prepare the Remedial Design Work Plan, and shall become the performance criteria for completion of the Remedial Action.

**B. COMPLETION OF THE REMEDIAL ACTION**

Completion of the Remedial Action will be based on the Respondent's demonstration

**STATEMENT OF WORK 1**

that the Performance Standards have been consistently attained and maintained in accordance with established protocols cited in Section V. (COMPLETION) Paragraph C. of this SOW. The Respondent's demonstration shall address potential seasonal variability that might affect test results.

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## **II. ROLE OF EPA**

Approval of submittals to EPA is administrative in nature to allow the Respondent to proceed to the next step in implementing the site remedies. It does not imply any warranty of performance or that the remedy, when constructed, will meet Performance Standards or will function properly and be accepted. Pursuant to Section XIV (EPA REVIEW OF SUBMISSIONS) of this Order, EPA retains the right to disapprove submittals during the Remedial Design and the Remedial Action. This action may be taken for contractors, plans and specifications, processes, and other submittals within the context of this Order.

## **III. RESPONDENT'S KEY PERSONNEL**

### **A. DESIGNATION OF PROJECT COORDINATOR**

Pursuant to Section IX (WORK TO BE PERFORMED) of this Order, the Respondent shall within 30 days of effective date this Order, submit in writing to EPA the name, title, and qualifications of their proposed Project Coordinator. Pursuant to Section XIV (EPA REVIEW OF SUBMISSIONS) of this Order and Section II (ROLE OF EPA) of this SOW, the Project Coordinator shall be subject to disapproval by EPA. The Project Coordinator is to be used in carrying out the overall coordination and management of all activities required under this Order. The Project Coordinator may be a member of the Respondent's staff, an independent contractor, or a member of the Supervising contractor's staff. The Project Coordinator shall not be an attorney for the Respondent in this matter.

### **B. REVIEW AND APPROVAL OF SUPERVISING CONTRACTOR**

Pursuant to Section IX (WORK TO BE PERFORMED) of this Order, the Respondent shall submit to EPA the name, title, and qualifications of their proposed Supervising contractor within 30 days of the effective date of this Order. Pursuant to Section XIV (EPA REVIEW OF SUBMISSIONS) of this Order and Section II (ROLE OF EPA) of this SOW, the Supervising Contractor shall be subject to disapproval by EPA. The Supervising contractor may come from within the ranks of the Respondent's own staff or through a contractual relationship with a private consulting entity. The Supervising Contractor shall be a Design Professional with experience in the remedies selected at this specific site. The Supervising Contractor may assume the role of Project Coordinator, Remedial

## **STATEMENT OF WORK 2**

Designer, Remedial Action Contractor, and Remedial Action Quality Assurance Official with the following exception. The Supervising Contractor shall not assume both the role of Remedial Action Contractor and Remedial Action Quality Assurance Official.

The Respondent shall demonstrate to EPA the proposed Supervising Contractor's professional reputation; professional registration; design experience and qualifications specifically required for the project; sufficient capacity in professional, technical, and support staff to accomplish the project within the required schedule; and sufficient business background and financial resources to provide uninterrupted services throughout the life of the project. The information submitted concerning the Supervising Contractor will include a written statement of qualification in sufficient detail to allow EPA to make a full and timely evaluation.

#### C. THE REMEDIAL ACTION QUALITY ASSURANCE OFFICIAL

Oversight by the Remedial Action Quality Assurance Official ("Remedial Action QAO") is used to provide confirmation/assurance to the Respondent and EPA that the selected remedy is constructed to meet project requirements. The Remedial Action QAO implements the Construction Quality Assurance Project Plan ("CQAPP") by selectively testing and inspecting the work of the Remedial Action Contractor. The Remedial Action QAO is required to be "independent" and autonomous from the Remedial Action Contractor. The Remedial Action QAO may come from within the ranks of the Respondent's own staff, the Remedial Supervising Contractor organization, or through a separate contractual relationship with a private consulting entity.

### IV. WORK TO BE PERFORMED

#### A. REMEDIAL DESIGN

Remedial Design is a process which begins with the preparation of a Remedial Design Work Plan ("RD Work Plan") which sets forth plans and schedules for those activities to be undertaken by the Respondent to develop the final plans, drawings, specifications, general provisions, and special requirements necessary to implement the remedies selected in the ROD and Amended ROD, pursuant to the RD Work Plan and Order.

The Remedial Design also shall include pre-design activities that include the preparation of planning documents to guide field and laboratory activities, sampling and analysis, and the refinement and evaluation of Remedial Design options.

##### 1. Remedial Design Work Plan for Soil Remedy

Within 60 days after the effective date of this Order, the Respondent shall submit for review, modification and/or approval by EPA a Work Plan for the soil remedy ("RD (Soil)

### STATEMENT OF WORK 3

Work Plan") for the design of the Remedial Action of the soil remedy at the Site. The RD (Soil) Work Plan shall provide for design of the soil remedy set forth in the Amended ROD. The RD (Soil) Work Plan shall be prepared in accordance with Section IX (WORK TO BE PERFORMED) the Order and this SOW, and upon its approval by EPA shall be incorporated into and become enforceable under this Order.

The RD (Soil) Work Plan shall describe in detail the tasks and deliverables the Respondent shall complete during the remedial design phase. Deliverables 1) through and including 5) shall be submitted 60 days after the approval date of the RD (Soil) Work Plan. The schedule for deliverables and tasks 6) through and including 11) shall be set forth by the Respondent in the RD (Soil) Work Plan and shall be subject to approval by EPA pursuant to Section XIV (EPA REVIEW OF SUBMISSIONS) of the Order. The major tasks and deliverables described in the RD (Soil) Work Plan shall include, but not limited to, the following:

- 1) Health and Safety Plan for field design activities to be prepared in conformance with applicable Occupational Safety and Health Administration ("OSHA") and EPA requirements, including, but not limited to OSHA regulations 29 C.F.R. 1910 (54 Fed. Reg. 9294)<sup>1</sup>;
- 2) Remedial Design Sampling and Analysis Plan;
- 3) Remedial Design Quality Assurance Project Plan ("RDQAPP");
- 4) Community Relations Plan;
- 5) Remedial Design Contingency Plan;
- 6) Field, sampling and analytical activities necessary to produce the Off-Site Sampling Results Report;
- 7) Off-Site Soil Sampling Results Report;

This report, at a minimum, must determine the horizontal and vertical extent of soils contaminated with arsenic above 30 ppm in the areas outside of the 6.8 acres that constituted the Crystal Chemical Company facility boundaries, and in the areas within the facility boundaries (i.e., fence lines and easements) that will not be covered by the multi-layer cap that is to be constructed during the Remedial Action. All offsite areas previously identified as contaminated will be resampled to verify the need for excavation. The sampling effort will include, but will not be limited to, adjacent properties, the Harris

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<sup>1</sup>EPA does not approve or disapprove the Health and Safety Plan, but does review it to assure its existence and require compliance with its terms as a part of the Consent Decree.

#### STATEMENT OF WORK 4

County Flood Control Channel, and all properties potentially affected by drainage from the site by way of the flood control channel. This report must also, at a minimum, calculate an excavation volume which is to include the known volume expansion factor, a potential achievable compaction percentage, and an estimate of the height of the soil mass once consolidated on the Crystal Chemical site itself.

- 8) Preliminary Soil Design submittal in compliance with paragraph IV.A.2.a. of this SOW;
- 9) Intermediate Soil Design submittal in compliance with paragraph IV.A.2.b. of this SOW;
- 10) Pre-final and Final Soil Design submittals in compliance with paragraph IV.A.2.c. of this SOW; and
- 11) Permit requirements for the Remedial Design and Remedial Action.

The RD (Soil) Work Plan shall be consistent with, and shall provide for implementing the soil remedy selected in the Amended ROD, and shall comply with EPA's "Superfund Remedial Design and Remedial Action Guidance, OSWER Directive 9355.0-4A".

EPA will review the RD (Soil) Work Plan pursuant to Section XIV (EPA REVIEW OF SUBMISSIONS) of the Order. EPA comments shall be satisfactorily addressed and incorporated into the RD (Soil) Work Plan by the Respondent, and a revised RD (Soil) Work Plan shall be resubmitted to EPA for review within 14 days or such other time as specified by EPA.

Upon approval of the RD (Soil) Work Plan by EPA, Respondent shall implement the RD (Soil) Work Plan according to the schedule in the approved RD (Soil) Work Plan. Unless otherwise directed by EPA, Respondent shall not perform further Work at the Site prior to EPA's written approval of the RD (Soil) Work Plan.

## 2. Design Reviews

Upon receipt of EPA's approval of the RD (Soil) Work Plan, the Respondent will implement the RD (Soil) Work Plan in accordance with its schedule as required by Section IX (WORK TO BE PERFORMED) of the Order. A minimum of three progressive design submittals will be required for EPA review. The purpose of the design reviews is to permit EPA to assess the design's feasibility to achieve the Performance Standards in accordance with the Amended ROD and Order. Design submittals will occur in three stages, described in Paragraphs a., b., and c., below.

## STATEMENT OF WORK 5

a. Preliminary (Soil) Remedial Design Submittal

Pursuant to Section VI of the Order, the Respondent shall submit a Preliminary Design (30% design completion). Preliminary Design begins with initial design and ends with the completion of the conceptual design. The Preliminary Design submittal shall include, but not be limited to, the following:

- 1) design criteria: during the preliminary design phase, concepts supporting the technical aspects of the design are defined in detail and presented in a "Design Criteria Report" prepared by the designer. The Design Criteria Report shall document that the design meets the technical requirements of the Amended ROD, including compliance with all ARARs, feasibility of all components of the selected remedy, and meets standard professional engineering practices.
- 2) Off-Site Soil Sampling Results Report;
- 3) preliminary plans, drawings and sketches;
- 4) required specifications in outline form;
- 5) a preliminary construction schedule; and
- 6) access agreements.

b. Intermediate (Soil) Remedial Design Submittal

According to the schedule in the approved RD (Soil) Work Plan, Respondent shall submit an Intermediate Design (60% design completion) to EPA for review and approval. It shall clearly show any modification of the design as a result of incorporation of comments furnished on the preliminary design submittal. The Intermediate Design submittal shall continue and expand on the contents of the Preliminary Design, and shall include, but not be limited to, the following:

- 1) approximately 60% of the completed drawings and specifications required for the final design;
- 2) draft Remedial Action Sampling and Analysis Plan;
- 3) draft Health and Safety Plan for Remedial Action activities to be prepared in conformance with applicable Occupational Safety and Health Administration

STATEMENT OF WORK 6



("OSHA") and EPA requirements, including, but not limited to OSHA regulations 29 C.F.R. 1910 (54 Fed. Reg. 9294)<sup>2</sup>;

- 4) draft O&M Plan;
- 5) draft Construction Quality Assurance Project Plan ("CQAPP");
- 6) draft Remedial Action Release Prevention/Contingency Plan; and
- 7) preliminary construction schedule.

**c. Pre-Final/Final (Soil) Remedial Design Review**

According to the schedule in the approved RD (Soil) Work Plan, Respondent shall submit the Pre-Final Design to EPA for review and approval. Upon approval by EPA, the Final Design shall be incorporated into and become enforceable under this Order. The pre-final design submittal shall include, but not be limited to, the following:

- 1) final plans and specifications;
- 2) Final Design Report detailing design compliance with Performance Standards, and addressing all issues and comments which arose during the design process. It shall clearly address any modification of the design as a result of incorporation of comments furnished during the preliminary and intermediate design submittal review;
- 3) Remedial Action Sampling and Analysis Plan designed to measure progress towards meeting remedial objectives and remediation goals established in the Amended ROD;
- 4) Health and Safety Plan for Remedial Action activities to be prepared in conformance with applicable Occupational Safety and Health Administration ("OSHA") and EPA requirements, including, but not limited to OSHA regulations 29 C.F.R. 1910 (54 Fed. Reg. 9294)<sup>3</sup>;
- 5) O&M Plan;

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<sup>2</sup>EPA does not approve or disapprove the Health and Safety Plan, but does review it to assure its existence and require compliance with its terms as a part of the Consent Decree.

<sup>3</sup>EPA does not approve or disapprove the Health and Safety Plan, but does review it to assure its existence and require compliance with its terms as a part of the Consent Decree.

**STATEMENT OF WORK 7**

- 6) request for proposals or invitation for bids for Remedial Action;
- 7) Construction Quality Assurance Project Plan ("CQAPP") to describe the site specific components of the quality assurance program which will ensure, with a reasonable degree of certainty, that the completed project meets or exceeds all design criteria, plans, and specifications. The CQAPP shall include, but not limited to, the following:
  - a. responsibilities and authorities of all organization key personnel involved in the design and construction of the site remediation;
  - b. identification and qualifications of the Remedial Action QAO to demonstrate he/she possesses the training and experience necessary to fulfill his/her identified responsibilities;
  - c. testing and sampling protocols use to monitor construction; and
  - d. identification of proposed sampling activities including sample size, sample locations, frequency of testing,
- 8) Remedial Action Release Prevention/Contingency Plan, to include at a minimum a Spill Prevention, Control and Countermeasures ("SPCC") Plan, as specified in 40 CFR 109; and
- 9) construction schedule.

## **B. REMEDIAL ACTION**

The Remedial Action process begins with the preparation of the Remedial Action Work Plan ("RA Work Plan") which sets forth plans and schedules for the construction of the remedies. The RA Work Plan shall be prepared as set forth in this SOW, in accordance with the design plans and specifications in the final design submittals, and Section VI of the Order.

The Remedial Action is the implementation phase of the site remediation. The Remedial Action ends when all requirements of Section IX (WORK TO BE PERFORMED), Subsections B (Remedial Action for Soil Remedy) and C (Remedial Action for Ground Water Remedy) of the Order have been met. Completion of the Remedial Action does not imply certification of Completion of Work as set forth in Section IX (WORK TO BE PERFORMED) Subsection D (Completion of Work) of the Order.

### **1. Remedial Action (Soil) Work Plan**

Pursuant to Section IX (WORK TO BE PERFORMED) of the Order, the Respondent shall

## **STATEMENT OF WORK 8**



submit within 30 days after EPA approval of the Final Design submittal for the soil remedy, the Remedial Action (Soil) Work Plan ("RA (Soil) Work Plan") for EPA review pursuant to Section XIV (EPA REVIEW OF SUBMISSIONS) of the Order and this SOW. The RA (Soil) Work Plan shall describe the Respondent's plan for implementation of the Remedial Action for the soil remedy within the terms and conditions of the Order and the SOW, as set forth in the Final Design submittal. It shall include, but not limited to, those items identified in Section IX (WORK TO BE PERFORMED), as well as:

- 1) selection of the Remedial Action contractor
- 2) execution of the contract for the completion of the Remedial Action;
- 3) schedule of Remedial Action activities, to include, but not limited to, construction, and operational and functional phases;
- 4) identification of and satisfactory compliance with permitting requirements;
- 5) identification of the Remedial Action Project Team, including key personnel, descriptions of duties and lines of authority;
- 6) a clear and concise description of the roles, relationships, and assignment of responsibilities among the Project Coordinator, Remedial Action QAO, Supervising Contractor, and the Remedial Action Construction Contractor;
- 7) Transportation and Disposal Plan pursuant to Section IX (WORK TO BE PERFORMED) of the Order and in accordance with the Off-Site Rule for contaminated material that is to be removed, transported, and disposed.
- 8) Strategies and schedule for implementing the following plans, prepared previously:
  - a. Remedial Action Sampling and Analysis Plan
  - b. Health and Safety Plan
  - c. O&M Plan
  - d. CQAPP
  - e. Remedial Action Release Prevention/Contingency Plan
- 9) Annual Remedial Action Report which summarizes the activities taken for the preceding year during the implementation of the Remedial Action. The first Annual Remedial Action Report shall be due one year from the lodging date of this Order. Succeeding Annual Remedial Action Reports shall be due in successive one year intervals on the anniversary date of the effective date of this Order;

#### STATEMENT OF WORK 9

- 10) Pre-Final Inspection
- 11) Remedial Action Report
- 12) Certification of the Remedial Action pursuant to Section IX (WORK TO BE PERFORMED) of the Order, and Section V, Paragraph C. of this SOW.
- 13) Completion of the Work pursuant to Section IX (WORK TO BE PERFORMED) of the Order, and Section V, Paragraph D. of this SOW.

## **2. Remedial Action (Ground Water) Work Plan**

Pursuant to Section IX (WORK TO BE PERFORMED) of the Order, the Respondent shall submit within 30 days after EPA approval of the Final Design submittal for the soil remedy, the Remedial Action (Ground Water) Work Plan ("RA (Ground Water) Work Plan") for EPA review pursuant to Section XIV (EPA REVIEW OF SUBMISSIONS) of the Order and this SOW. The RA (Ground Water) Work Plan shall describe the Respondent's plan for implementation of the Remedial Action for the ground water remedy within the terms and conditions of the Order and the SOW, as set forth in the Final Design submittal. It shall include, but not limited to, those items identified in Section IX (WORK TO BE PERFORMED), as well as:

- 1) selection of the Remedial Action contractor
- 2) execution of the contract for the completion of the Remedial Action;
- 3) schedule of Remedial Action activities, to include, but not limited to, construction, and operational and functional phases;
- 4) identification of and satisfactory compliance with permitting requirements;
- 5) identification of the Remedial Action Project Team, including key personnel, descriptions of duties and lines of authority;
- 6) a clear and concise description of the roles, relationships, and assignment of responsibilities among the Project Coordinator, Remedial Action QAO, Supervising Contractor, and the Remedial Action Construction Contractor;
- 7) Transportation and Disposal Plan pursuant to Section IX (WORK TO BE PERFORMED) of the Order and in accordance with the Off-Site Rule for contaminated material that is to be removed, transported, and disposed.
- 8) Strategies and schedule for implementing the following plans, prepared previously:

## **STATEMENT OF WORK 10**

- a. Remedial Action Sampling and Analysis Plan
- b. Health and Safety Plan
- c. O&M Plan
- d. CQAPP
- e. Remedial Action Release Prevention/Contingency Plan

9) Annual Remedial Action Report which summarizes the activities taken for the preceding year during the implementation of the Remedial Action. The first Annual Remedial Action Report shall be due one year from the lodging date of this Order. Succeeding Annual Remedial Action Reports shall be due in successive one year intervals on the anniversary date of the effective date of this Order;

10) Ground Water Extraction Evaluation Report which provides and evaluation of the performance of the ground water extraction and treatment system on an annual basis. The evaluation shall be based on the monitoring of the system and its impact on the ground water plume at the site. The information shall be used to determine the effectiveness of the ground water extraction and treatment system. Not later than 90 days following the anniversary date of the initiation of the ground water extraction and treatment system, the Respondent shall submit a Ground Water Extraction Evaluation to EPA providing the results of the ground water system evaluation for the preceding year. Succeeding Ground Water Evaluation Reports shall be due in successive one year intervals on the anniversary of the date of the first report.

11) Pre-Final Inspection

12) Remedial Action Report

13) Certification of the Remedial Action pursuant to Section IX (WORK TO BE PERFORMED) of the Order, and Section V, Paragraph C. of this SOW.

14) Completion of the Work pursuant to Section IX (WORK TO BE PERFORMED) of the Order, and Section V, Paragraph D. of this SOW.

### 3. Operational and Functional

Pursuant to the NCP, 40 CFR 300.435(f)(2), a remedy becomes "operational and functional" either one year after the Remedial Action construction is complete, or when the remedy is determined by EPA to be functioning properly and is performing as designed, whichever is earlier. The schedule for and the activities associated with the performance of the remedy during the operational and functional phase shall be set forth in the individual Remedial Action Work Plans for the soil and ground water remedies.

## STATEMENT OF WORK 11

Upon the completion of the operational and functional phase of activities for each remedy at the site, the Respondent shall prepare a Remedial Action Report for each remedy pursuant to Section V (COMPLETION) of this SOW.

For the soil remedy as described in the Amended ROD, the remedy will be considered operational and functional one year after the Remedial Action construction is complete, or when the remedy is determined by EPA to be functioning properly and is performing as designed, whichever is earlier.

For the ground water remedy as described in the 1990 ROD, upon completion of the Remedial Action construction of the extraction and treatment system, the remedy will be considered to be operational and functional by EPA for a period of one year, or when it is determined by EPA to be performing properly and as designed, whichever is earlier.

#### 4. Long-Term Remedial Action

For the ground water remedy as described in the 1990 ROD, once the remedy is determined to be operational and functional, the remedy will be considered to be in the Long-Term Remedial Action ("LTRA") phase. The schedule for and the activities associated with the performance of the remedy during the LTRA phase shall be set forth in the Remedial Action (Ground Water) Work Plan. The LTRA phase is to continue until such time as 10 years of actual operation of the extraction and treatment system has passed.

The soil remedy as described in the Amended ROD will not have a LTRA phase.

#### C. OPERATION AND MAINTENANCE

Operation and Maintenance ("O&M") measures are initiated after the remedies have achieved the remedial objectives and remediation goals as set forth in the ROD and in the Amended ROD, and O&M shall include all activities described in the O&M Plan, the scope of which is to describe activities required to maintain the effectiveness of the Remedial Action.

O&M for the soil remedy as described in the Amended ROD begins after the remedy has achieved the remedial objectives and remediation goals as specified in the Amended ROD and in this SOW, and when the Remedial Action for the soil remedy is determined to be operational and functional by EPA.

O&M will follow the completion of the LTRA phase of activities for the ground water remedy. Restoration of the ground water will be considered administratively "complete" when ground water has been restored to levels specified in the 1990 ROD.

## **V. COMPLETION**

### **A. PRE-FINAL INSPECTION**

Upon completion of the Remedial Action construction for each remedy and prior to the commencement of the operational and functional phase for each remedy, Respondent shall conduct a pre-final inspection of the remedy. Within 60 days of completing the inspection, the Respondent shall submit to EPA a Pre-Final Inspection Report. A Pre-Final Inspection Report shall be submitted for the soil remedy, and a Pre-Final Inspection Report shall be submitted for the ground water remedy. This reports shall document the completion of physical construction of the remedy, or the installation of the required elements of the remedy.

If, after review of the written report, EPA determines that any portion of the construction has not been completed in accordance with the approved Final Remedial Design, EPA will notify the Respondent in writing of the activities that must be undertaken to complete construction in accordance with the approved Final Remedial Design. Upon receipt of notice from EPA, Respondent shall submit a schedule for performance of such activities to EPA for review and approval.

Upon completion of the activities necessary to complete construction, an inspection shall be conducted. If EPA concludes that the Remedial Action construction has been completed in accordance with the approved Final Remedial Design, EPA will approve the Pre-Final Inspection.

### **B. REMEDIAL ACTION REPORT**

Upon the completion of the operational and functional phase of activities at the site, the Respondent shall prepare a Remedial Action Report for each of the remedies which documents that all items contained in the Order and any incorporated documents pursuant to the construction of the Remedial Action have been completed. The report shall include a construction chronology, a list on construction modifications, pre-final inspection corrections, documentation substantiating that the remedy is functioning properly and is performing as designed, and As-Built Drawings of the project.

### **C. CERTIFICATION OF COMPLETION OF REMEDIAL ACTION**

Within 90 days after the Respondent concludes that the Remedial Action has been completed and that all the Performance Standards set forth in Section I (INTRODUCTION) of this SOW have been met, the Respondent shall request the scheduling of a pre-certification inspection, pursuant to Section IX (WORK TO BE PERFORMED) of the Order. There will be separate certifications of completion for the soil and ground water remedial actions. Pre-certification and certification inspection participants will include the EPA Remedial Project Manager, designated EPA Oversight

Officials, and other agencies with a jurisdictional interest in attendance. The purpose of the inspection(s) is to determine whether all aspects of the plans and specifications have been implemented at the site, and whether the remedies are operational and capable of meeting Performance Standards. The final O&M Plan will be presented for review prior to scheduling of the pre-certification inspection to allow comments on the plan simultaneously with inspection comments. If any items have not been completed, the Respondent shall develop a list specifying the outstanding items which require completion or correction before acceptance of work. Because the ground water remedy involves treatment, acceptance of work will not be granted until the Respondent demonstrates that the Performance Standards are being met.

A written report requesting certification shall be submitted to EPA for review after completion of the pre-certification inspection, pursuant to Sections IX (WORK TO BE PERFORMED) and XIV (EPA REVIEW OF SUBMISSIONS) of the Order. EPA will notify the Respondent of any corrective actions necessary to satisfactorily complete the Remedial Action and achieve Performance Standards if deficiencies are found to exist.

A certification inspection shall be conducted when all corrective action items have been completed. All items specified to require correction shall be reinspected, and all tests that were originally unsatisfactory shall be conducted again. If EPA concludes that the Remedial Action has been fully performed in accordance with the Order and that Performance Standards have been attained in accordance with Section I (INTRODUCTION) of this SOW, certification will be granted in writing by EPA.

#### D. CERTIFICATION OF COMPLETION OF WORK

Work at a site shall be considered complete when all Remedial Actions required to attain and maintain the protection of human health and the environment are complete, all operation and maintenance activities are complete.

Pursuant to Section IX (WORK TO BE PERFORMED) of the Order, within 90 days after the Respondent conclude that all phases of work have been fully performed, the Respondent shall submit a written report by a registered professional engineer stating that all work has been completed in full satisfaction of the Order and this SOW.

If, after review of the report by EPA, EPA determines that any portion of the work is not complete, EPA will inform the Respondent in writing of the activities required to complete the work. EPA will provide a schedule for the performance of the activities consistent with the Order and this SOW or require the Respondent to submit a schedule to EPA for approval.

If EPA concludes, based on the initial or subsequent requests for Certification of Completion of Work by the Respondent, that work has been fully performed in accordance with the Order, EPA will so notify the Respondent in writing.

#### STATEMENT OF WORK 14